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Excursions in Science

Edited by NEIL B. REYNOLDS

and ELLIS L. MANNING

IN *Excursions in Science*, thirty scientists present, in simple language, thirty-five stories of their respective sciences. The subjects range from organic chemistry to atomic physics, from archeology to astronomy. But instead of rules and definitions, they tell us what happens to the food we eat, what causes lightning, how the vacuum tubes in our radios work, what causes the tides. They take us, as the title indicates, on excursions into the world around us, showing how the light of science gives new meaning to the everyday things of life.

Unlike most scientific books for laymen, these *Excursions* have not undergone a translation-like process at the hand of an interpreter. Each *Excursion* is the work of a scientist who has been trained in his particular field, who has worked in it, who has almost literally eaten and slept with it. The emphasis is on what he, himself, thinks important, not what someone else thinks should be important.

Many of the contributors are well known, and a number have recently gained special recognition in their sciences. Dr. Langmuir, of course, is famous

(Continued on back flap)

(Continued from front flap)

for his work in electronics and surface films. Dr. Blodgett's work in "invisible glass" has recently gained wide attention. Dr. McEachron's studies of lightning led to the artificial lightning exhibit which has been one of the most popular features of the General Electric exhibit at the New York World's Fair. Dr. Haskins is the author of a recent book, *Of Ants and Men*, which has been well reviewed.

The editors, Neil B. Reynolds and Ellis L. Manning, are respectively Special Writer for the General Electric Company and Supervisor of Science, New York State Department of Education. Both were formerly Physicists in the Research Laboratory of the General Electric Company.

"Engrossing reading."—*Book-of-the-Month Club News*.

"Fascinating."—*Nature Magazine*.

"Some of the most interesting stories of this year."—*Cleveland Plain Dealer*.

"Admirable clarity and concreteness. . . . Excellent."—*Baltimore Sun*.

"Should win a wide popularity."—*Hartford Courant*.

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EXCURSIONS IN SCIENCE

*“Somebody is always reflectively monkeying
with some of the parts of an infinite universe.”*

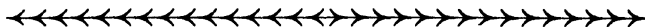
W. R. W.

EXCURSIONS IN SCIENCE



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To

WILLIS RODNEY WHITNEY

**VICE-PRESIDENT IN CHARGE OF RESEARCH
OF THE GENERAL ELECTRIC COMPANY, THE
EDITORS AFFECTIONATELY DEDICATE THIS
VOLUME**

PREFACE



TO APPRECIATE music, one does not have to be a virtuoso, or a performer at all for that matter. Indeed, it may be that the informed but nonprofessional listener gains as much pure enjoyment from a concert as does the more critical student of musical technique.

What is true of music, and of the other arts, may be, in its own fashion, equally true of science. We cannot ignore the results of science; they lap us round, they shape and alter increasingly the course of our activities. Yet their origin is, to most of us, a mystery. This is our loss, for just as a layman's knowledge of the instruments that make up a symphony orchestra may sharpen his appreciation of its rendition—whether of Beethoven's *Eroica* or of the *Rhapsody in Blue*—so a little knowledge of the scientist's problems, his tools, and most of all his mental outlook may serve to sharpen our appreciation of the gifts science has to offer.

Such knowledge is not beyond the grasp of anyone, for the materials with which the scientist deals are, after all, the things with which we are all most familiar.

Preface

Laboratory examination is only an extension in degree of intelligent observation. Scientific reasoning is nothing more than systematized common sense.

In May, 1936, the General Electric Company instituted a radio program, called The Science Forum, designed to present the meaning, scope, and several purposes of modern scientific research and engineering in language that could be understood by the intelligent layman. As part of that program, workers in many fields of science were invited to present short talks on their particular fields of study.

Because the material presented seemed too valuable to serve only the ephemeral purposes of the radio, the editors have gathered a selected group of these talks into this present form. Because, in each section that follows, we shall be venturing into a different field of scientific study under the guidance of a writer experienced in that field, the name *Excursions in Science* has been chosen. These excursions follow no fixed itinerary; by intent they range from astronomy to physiology, from atomic physics to archeology. The world about us is filled with interesting things to explore, and we want to visit as wide a variety of them as time and our appetite for adventure permit.

A manuscript prepared for broadcasting is not always in a form most suitable for publication. The

Preface

talks have, therefore, in certain cases, been somewhat altered and abridged. But in every case it is the original author who speaks; the opinions expressed are his. The editors are pleased to acknowledge their indebtedness to these authors, to the General Electric Company, and in particular to the General Electric Research Laboratory for aid in making possible these *Excursions in Science*.

NEIL B. REYNOLDS,
ELLIS L. MANNING.

SCHENECTADY, N. Y.

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EXCURSIONS IN SCIENCE

Excursions in Science

I think this is a mistaken attitude. I believe there never was a time when there were so many simple experiments that could be made that can lead to important results. Of course, it is perfectly true that many of the problems that scientists have to face today require apparatus that would be quite beyond the means of the ordinary individual scientist. Such problems as these are best attacked in university laboratories or in big industrial laboratories where extensive facilities are available.

But I want to describe some of the simple problems which used to interest me when I was a boy—problems which can be experimented on in a very simple way and yet which require a great deal of thought to explain.

For example, I have in my pocket a fountain pen and a pencil. The pencil is a round one, and the pen has a considerably larger diameter than the pencil. If I sit down at a table and place the pencil across the pen, I find that I can balance the pencil on the pen by carefully moving the pencil back and forth until the center of gravity comes just over the point at which it touches the pen. When I balance the pencil in this way, and then displace it a little by pushing one end down, the pencil, instead of falling off the pen,

Simple Experiments in Science

oscillates back and forth with a definite period of oscillation, like a pendulum.

Yet, if you try to do the thing the other way around and put the pen on top of the pencil, you will find that you cannot obtain a balance. I used to wonder about this when I was a young boy, so I made experiments with pencils of different sizes. And I came to the conclusion that one pencil can be balanced on another only if the top one has a smaller diameter than the lower one. I wasn't able to figure out the reason for this, but later on when I was a sophomore in college and began to study mechanics I was able to work out the solution by myself, and had a lot of fun in doing it.

Here is another simple experiment that anyone can try. Take a glass of water and sprinkle into it some crumbs of dry bread or toast that have been broken into fine particles by rubbing between the fingers. Then stir the water in the glass with a spoon and watch what happens. The crumbs circulate around with the water, being pretty uniformly distributed through the whole mass of liquid. Gradually you see the crumbs settle to the bottom and heap up in a little conical pile in the center of the glass. The same thing happens to some extent when you put sugar in a cup of clear tea and stir it.

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Now, why do the bread crumbs collect in the middle at the bottom of the glass? Different people will give you many different explanations. The most common one is that the crumbs cannot settle near the edge because there the water is moving over the surface of the glass so fast that the particles are swept along by the current. At first that seems a reasonable explanation. But in a case like this it is better to try to settle the question by experiment rather than to argue over the pros and cons of different possible explanations.

Suppose, instead of rotating the water in the glass by stirring it, we try to rotate the glass around the water—that is, to have a glass full of water containing some bread crumbs in suspension and then start turning the glass at a uniform speed. If the explanation just given is correct, then we should naturally expect that the crumbs would again collect in a little cone in the middle of the glass, because when the water is still and the glass is rotating the relative motion of the water and the glass is the same as before.

If you try to think of a method for rotating the glass, you will probably find it difficult to do in a simple way. The simplest way that I've been able to think of is to take a large mixing bowl, such as can be found in every kitchen, and fill it with water and float in the middle of it a smaller, empty bowl. Then give the inner bowl a

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spin and it will turn very nicely at any speed you want.

Next, take the glass that has the bread crumbs in it, agitate the water with a spoon so as to bring the crumbs into suspension, taking care not to make the water rotate as a whole in either direction. Then, before the crumbs have settled, put the glass into the bottom of the smaller bowl and set this in rotation. If you try this, you will find that all the crumbs will settle in a nice ring heaped up against the outer edge of the glass, and there will be no crumbs in the center. So evidently the explanation suggested in the beginning is not right.

If you sit down carefully at a table and watch the motion of the bread crumbs and the water in both of the experiments, you will, I think, begin to understand what it is that makes the bread crumbs pile in a cone at the center in one case and spread out in a ring in the other case. What seems the key to the solution is found by watching the top surface of the water. In the first experiment, when you rotate the water while the glass is still, you find that there is a little depression in the surface of the water near the middle. But in the second experiment, when you rotate the glass while the water is still, you do not see this depression.

Now I am not going to give the answer to this problem. I suggest that those who are interested try to

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work it out for themselves and see whether they can reach a satisfactory explanation of the things they observe.

There are many interesting experiments that you can make with soap-bubble films that will give you a lot to think about. One of the prettiest is to make an open framework of wire that has the form of the 12 edges of a cube, with an extra wire to serve as a handle. Now make up a soap solution. (You will get bubbles that last longer if you put a little glycerin into the solution.) Dip the whole wire frame down into the soap solution and bring it up slowly. You will see some very interesting geometrical figures, especially if you dip it a second and third time.

Just before the soap films break you'll notice some beautiful iridescent colors. To explain these you need to understand the wave theory of light. The colors are due to the interference of light reflected from the front and from the back side of the films. The particular colors that you get depend upon the relation of the thickness of the film to the wave length of the light. If you use light of a known wave length, such as from sodium-vapor lamps, then, instead of colors, you will see alternating light and black bands which run across the films. From these bands, it is possible to calculate the exact thickness of the films.

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Dr. Katharine Blodgett and I have been using just such a simple method, which does not require expensive or complicated apparatus, to measure the sizes of molecules that are only one ten-millionth of an inch in diameter. We can also use this method to detect extremely small amounts of many chemical substances. In fact, we can in this simple way find the presence of many substances, such as copper, in water, even if they are present only to the extent of one part in a *billion*. We hope that these methods are going to enable biologists and doctors to detect and measure such substances as toxins and antitoxins in even smaller quantities than can now be detected by injecting these substances into animals.

Protein forms an essential part of all living things. It consists of molecules that are very large in comparison with those of most other substances. For example, some proteins have been found that have a molecular weight of several millions, although some other proteins have weights of only 30,000. The methods of measuring these weights have involved the use of centrifugal force about a million times as great as the force of gravity. Such methods often require apparatus that costs hundreds of thousands of dollars, and each investigation is an elaborate research taking days or weeks of preparation.

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By using the colors that we see in soap bubbles, and with apparatus that costs only a few dollars, and in a time of less than half an hour, it now becomes possible to make measurements of the sizes of these molecules and to get many other characteristics of these substances that it was not possible to get before. I mention these points as illustrations of the fact that it is still possible today to find very simple methods for obtaining scientific results.

ATOMS AND THEIR FAMILY RELATIONS

by DR. E. G. ROCHOW



DR. ROCHOW, born in Newark, New Jersey, was graduated in chemistry from Cornell University, worked as a research chemist for the Holowax Corporation, and returned to Cornell to take his Doctor's degree. In 1935 he joined the General Electric Research Laboratory, where he is at present working in the field of ceramics and inorganic insulating materials.



IF YOU have read a good detective story recently, you may have admired the way the brilliant investigator unraveled a knotty mystery with such unruffled finesse. And we, too, are about to pay our respects to a man who solved a longstanding mystery in a very unusual way. Just as truth is stranger than fiction, so the solution that this man proposed, and the way he proved his case, are far more remarkable than the pre-fabricated tales of the story writers. Moreover, this particular problem that we shall consider is not remote or unimportant; it concerns us and the world around us. Specifically, it concerns the atoms of which we and our homes are made.

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Just as you find is the case in most detective stories, someone had to do the groundwork and uncover a great many facts before even a start could be made on this problem of atoms and how they are related. Of course, the earliest men had started tinkering with stones and metals and fire and water, and they soon began to take things apart out of curiosity.

Several hundred years ago, when the art of alchemy was developing into the service of chemistry, chemists were learning how to take apart wood and water and stones, just as an inquisitive youngster takes apart an old alarm clock. Through the years it gradually became evident that the familiar objects around us, as well as our own bodies, were made of a rather limited number of elementary substances, which in turn could not be taken apart into simpler materials. It was encouraging to find that everything contained one or more of these elementary substances, for here at last were the building blocks of nature, out of which the world was fashioned.

These elementary substances were called *elements* for short, and they were studied alone in order to find out how they behaved and how they joined with other elements to make familiar materials. Then, about 150 years ago, men began to learn *how much* of one element would join with a fixed weight of another.

Atoms and Their Family Relations

It had been surprising to find that water, when taken apart, always contained the two elements hydrogen and oxygen, and never any others. Now it was equally surprising to find that in 9 pounds of water there were 8 pounds of oxygen and 1 pound of hydrogen—never any more or any less. Water was water. It always contained just the same proportions of these two elements, or else it wasn't water.

From this point it was easy to reach the third step in experience. Water could be synthesized, or put together, by combining eight parts of oxygen with one part of hydrogen. Moreover, it now became possible to take apart water and put it back together again, the whole process being easier than taking apart a clock and putting it together again.

The next big advance was the idea of atoms. When a definite amount of one element combines with a fixed amount of another, this immediately suggests that a number of chunks of one element are combining with a number of chunks of the second element, the numbers being limited and definite because the chunks combine in only one way. The chunks were politely called *atoms*, because the ancient Greeks had argued about the existence of atoms without being able to prove that they existed. An atom, then, is simply the smallest part of an element that can be depended on

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to behave like the element, and so of course all atoms of a given element are chemically alike.

Now, an atom is very small and very light. It takes some 1700 million billion hydrogen atoms to make 1 ounce—hydrogen atoms being the lightest ones we know. Even the heaviest atoms would run 18 million billion to the ounce, and you can see that chemists would be driven to distraction if they had to juggle such figures in order to make a simple calculation. For most work, chemists do not care about the weight of an atom in ounces, and a century ago they did not even know it. Since the hydrogen atom is the lightest, and the oxygen atom is found by experiment to be 16 times as heavy, it is possible simply to call the weight of the hydrogen atom 1, and the weight of the oxygen atom 16. This number is just a shorthand notation; all it can tell us about an atom is that the single atom is thus-and-so times as heavy as the hydrogen atom. This gives us a scale of relative atomic weights, and as you have seen, there is nothing mysterious about them.

We have followed the method used by the chemists to learn about matter and what it is made of, and we have seen how they tracked down the common elements and found the weight of their atoms. These early fact-finding chemists thought they were getting

Atoms and Their Family Relations

at the root of things. Actually, they were creating a mysterious puzzle—since no one knew what connection there was among all these elements, what order there was in all this chaos of facts. It was all very well to reduce things to atoms, but unless there was some common relationship the chemist was really just as badly off as before. Instead of learning about the properties of every material, he now had to learn the individual behavior of every isolated element. Furthermore, new elements were discovered now and then, and there was as yet no reason to think that more new discoveries might not keep on coming indefinitely.

Thus the stage was set for a master mind to step in and show some sort of connection among all these facts. The man who did so was not a detective, and perhaps he was more of a philosopher than a chemist. But he found a solution that was so startling, so unusual, that even the most credulous people found it impossible to believe him at first.

This man was an obscure Russian professor named Dmitri Ivanovitch Mendelyev. He took the 58 elements that were known, and he tagged each one with the atomic weight that he considered the most reliable. His problem was then to find the link that connected *all* of them.

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Mendelyev finally hit upon a radical idea: that *the properties of an element depend upon its atomic weight*. If the atoms were arranged in the order of their weights, they showed distinct changes in going from one to the next, but every so often they repeated some general properties. Their behavior changed in waves or cycles which repeated regularly, and so the atomic weight of an element automatically placed it in a certain wave or cycle where its neighbors were known, and its relatives occupying the same place on other waves could be seen very easily. Because of this cyclic behavior, Mendelyev called his scheme the periodic system.

Now, to say that the behavior of an element depends upon its weight alone is a very unusual thing. We do not have a parallel in everyday life. Suppose that all the suspects involved in a murder mystery were gathered together in one room at the police station—58 of them. In walks the detective and says, "If you arrange these people according to their weights, you will see that they divide naturally into eight families, and I can tell from this family arrangement just how each one will act in a given situation." You would call the detective crazy.

Mendelyev published his idea, and people did call him crazy. For two years he struggled to get his

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scheme published in a well-known scientific journal, where the best minds could judge it. Eventually it did appear in German, and immediately some of the best minds set out to prove him wrong. Because Mendelyeev's scheme was very weak in spots, this did not seem difficult.

To picture his plan, Mendelyeev had written down the elements in a horizontal row, starting with the lightest and proceeding in order. The eighth element resembled the first, so he began another row underneath the top row. The fifteenth element again resembled the first, so he began still another row. This went on until the result looked very much like your monthly calendar—the elements were in rows of seven, like the days of the week, and the similar elements fell into vertical groups like all the Sundays or all the Mondays.

But unlike your calendar, this so-called periodic table had empty spaces in it. Mendelyeev had tried to put the elements in the exact order of their weights, but occasionally one did not fit, so he blithely skipped a space or two and placed the element where he thought it belonged. There were half as many blank spaces as there were filled spaces, so the thing was not very convincing.

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It was easy for the critics to point out that the then known elements didn't *fall* into families; they said that Mendelyeev had simply arranged them that way and then had claimed that the arrangement was a natural law. In other words, they accused him of cheating at his own game of solitaire.

To this Mendelyeev answered that the empty spaces represented undiscovered elements, and that his faith in the periodic system was so great that he would use the system itself to predict the properties of these unknown elements. Picking out three important empty spaces, he thereupon told the world at large where these elements might be found, how they would act, what their atomic weights would be—in short, he seemed to know as much about the unknown elements as about the known ones.

Very wisely, Mendelyeev did not seek these unknown elements himself. There were plenty of chemists anxious to prove him right or wrong, and the search went on in dozens of places. It was not long before signs of the missing elements began to appear, and eventually some of the severest critics were the very ones who proved that the Russian professor was right. The predicted elements were found where he said they would be, and they behaved just as he said they

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would. The periodic system triumphed, and its author was vindicated.

Let us see how good a job this detective had done. For the element which later was named germanium, he predicted an atomic weight of 72; the weight was found to be $72\frac{1}{2}$. He said that its density would be $5\frac{1}{2}$, and it was $5\frac{1}{2}$. He predicted a compound with chlorine that would boil below 100° and have a density of $1\frac{9}{10}$. This compound was made; it boiled at 86° , and its density was $1\frac{9}{10}$. He even predicted that the element would combine with the ethyl group of ordinary alcohol to give a liquid boiling at 160° . When such a compound was made, it *did* boil at 160° .

There could be no doubt that Mendelyev was right and that he had found law and order among the elements. The faults of the scheme were cleared up in time, and at present all but a very few of the 92 elements of the periodic table are well known. A host of confusing chemical questions have been answered by the table, and today it is one of the best established and most useful things in the whole field of chemistry.

WHERE HUMAN ENERGY COMES FROM

by DR. JAMES W. MAVOR

←←←←←←←←←←←←←←←←→→→→→→→→→→→→→→→→→

DR. MAVOR, a native of Glasgow, Scotland, attended Trinity College, Cambridge University, England. He received his degree of Doctor of Philosophy from Harvard University. He was Austin Teaching Fellow at Harvard, was Instructor in Zoology at the University of Wisconsin, and went to Union College as Assistant Professor in 1916. Since 1924 he has been Professor of Biology and head of that department. He is the author of *General Biology*, published by The Macmillan Company in 1936.

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THE human body, or the body of any animal, for that matter, may be looked upon as a machine that does a certain amount of work as a result of being supplied with a certain amount of fuel in the form of carbohydrates, fats, and proteins. The energy to do the work comes from the oxidation, or burning, of these materials in the body.

It is important to distinguish between the external work done by the body and the internal work that goes to maintaining the body temperature and to carrying on the various internal vital functions. The external work may be useful, as when the individual is

Where Human Energy Comes From

engaged in pumping water from a well; or it may lead to no particular accomplishment, as when the individual uses a rowing machine. In the first case a certain amount of water is lifted through a certain height; in the second case the work on the rowing machine goes in friction and is dissipated as heat. In both cases the body may be said to do external work. The internal work, whether it goes to maintaining the body temperature, to pumping the blood round the body, or to taking the air into the lungs, either goes to building up the body or becomes dissipated as heat given off.

Energy is usually measured in units called calories. The kilogram calorie, or larger Calorie, is the energy required to raise the temperature of 1 liter, or approximately 1 quart, of water 1° centigrade, or $1\frac{4}{5}^{\circ}$ Fahrenheit. The amount of energy which a given amount of food yields when oxidized can be determined in an apparatus called a calorimeter, or calorie-measurer, which absorbs and measures the heat generated. By making calorimetric determinations of the food eaten by a man, and similar calorimetric determinations of the materials excreted, it is possible to determine exactly how many Calories of chemical energy the man actually takes into his body. If the body is a machine so far as the energy transformations in it are concerned, it ought to be possible, if

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there is no increase in the body weight during the time of the experiment—that is, if there is no energy stored in the body—to account for the Calories taken into it in terms of work done.

Such experiments have been carried out on the human subject. Large calorimeters have been built in which men have lived for weeks, with the amount of energy supplied to them as food carefully measured, and the amount of energy given off in the form of body heat and work also measured. One method of measuring the amount of work done is to have the man ride a stationary bicycle, the back wheel working against a brake. From the number of revolutions of the wheel and the force on the brake, the amount of work done can be calculated. The results of many such experiments carefully performed with more or less elaborate apparatus have shown that, in respect to the energy transformations within it, the human body does behave like a machine.

The average working man requires about 3000 Calories per day. But we should like to know the amount of energy needed just to maintain a person's vital activities in the resting condition, that is, when he is doing no outside work. This is called the *basal metabolism*. The determination is usually made before breakfast and with the person lying in bed, and the

Where Human Energy Comes From

calculation is based on the carbon dioxide given off rather than on the food taken in. Since under the conditions no external work is done, all of the energy liberated goes into heat. The average rate at which this heat is produced in a normal adult is 1500 to 1800 Calories per day. Thus, in a normal man, somewhat over one-half of the energy value of the food substances taken into his body goes to maintaining his body temperature and for such essential vital activities as breathing and the beat of the heart. The other part is available for the performance of external work.

Man is notoriously fussy about what he eats, but the walls of his intestine are even more particular about what they absorb. Carbohydrates, fats, and proteins must be broken down or digested before they can pass through the delicate cell membranes to enter his body. As a result, the energy comes to him only in certain special substances. These are a simple sugar (glucose), a few fatty acids, glycerin, and some 20 amino acids. Water, a number of mineral salts, and the much-publicized vitamins are also required; but while these are necessary, they do not contribute any appreciable amount of energy.

The idea crops up from time to time, usually in the comic supplements, that some chemical genius may discover a mixture of synthetic products which could

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be made into a small pill and which would provide a substitute for a square meal. Thus one might get his lunch at the back of the drugstore instead of in the front. It is a myth. The question may be put as follows: what is the smallest form or least weight in which 3000 Calories can be made available for absorption in the human intestine? It cannot be dynamite, simply because we are not made that way. Practically, it must be in the form of carbohydrates, fats, and proteins. Now, one gram of carbohydrate or a gram of protein yields approximately 4.1 Calories, and one gram of fat yields approximately 9.3 Calories. A simple calculation shows that if the food consisted entirely of fat, the daily ration would weigh 323 grams, about two-thirds of a pound, and if it contained a balanced diet it would weigh at least a pound. No small pill! Do what we may, we cannot get away from the fact that we are human.

Man is therefore entirely dependent on plants and other animals for his food materials. In the ultimate analysis, green plants are the only manufacturers of food substances, and they depend on the sun for the energy to carry on the process. The average amount of radiant energy received by one square yard of the earth's surface in our latitude, taken over the year and allowing for dull days and bright days, is about 3000

Where Human Energy Comes From

Calories per day. So, if all the energy that comes to one square yard of the earth's surface in our latitude could be used to manufacture food substances, the amount would supply the needs of one man. This would seem to suggest that the kind of Utopia in which efficiency is made the ideal may be one in which there is standing room only.

One may ask: Just how efficient is modern agriculture? Looked upon as a machine for manufacturing food materials, how efficient is the green plant and how efficiently is the green plant used by man? When a green leaf is exposed to the sun under conditions favorable for photosynthesis, approximately 1 per cent of the radiant energy received by it is transformed into chemical energy in the form of sugar or starch. Not all of this sugar or starch—indeed, only a small portion—is available for human food. In the first place the plant must feed itself and provide the materials for its own tissues, including the cellulose of its cell walls. In the second place, the food materials must be in a form that can be utilized by man. We are unable to make a meal of grass, like a horse, bark like a deer, or wood like a termite. True, we can feed the grass to cattle and get milk or beef in return, but we cannot eat all of a steer.

The result is that it requires on the average at least one acre to produce the food required by one man for

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one year. Recorded in terms of the radiant energy received from the sun and the Calories in the food, the efficiency is about $\frac{2}{100}$ of 1 per cent. This is, of course, nothing for an engineer to boast about. But one must remember that no other commercial method is really available for the manufacture of food on a large scale, and that the end product, human protoplasm, is unique.

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rated from each other, so that, starting on the 180th meridian, where each day is born, and circling westward, moving 15 degrees of longitude just before each succeeding hour, he could have celebrated the coming of the new year 24 separate and distinct times.

For the astronomers the new year begins at the instant when the earth reaches a certain point in its orbit relative to the stars. If we celebrated the beginning of the new astronomical year, there would be a simultaneous outburst all over the earth—morning, noon, afternoon, or in the wee small hours, whatever the local time of day happened to be. But people are determined that the new year shall begin for each of us approximately at midnight—at the time that the earth, whirling on its axis, has placed us farthest from the sun. Since it requires 24 hours for all parts of the earth to traverse this position, the instants for the popular initiation of New Year's Day last this long.

In passing, it is interesting to note that the point on the earth's orbit which has been selected by the astronomers to mark the new year is the earth's position not on January 1 but on March 21—not New Year's Day but the vernal equinox.

To measure time, some recurring phenomenon is indispensable. As examples we have the pulse, a pendulum, the phases of the moon, sunrise, the vibra-

Time

tion of an organ pipe or a quartz plate. Galileo used his pulse in discovering that the period of oscillation of the chandelier in the church at Pisa did not change as it swung through a wide or a narrow arc. This discovery led to the invention of the pendulum clock. The American Indian used the moon to mark the passage of time. We base our time division of hours, minutes, and seconds on an average apparent daily motion of the sun around the earth; but our year, as I have said, is based on the earth's returning to the same position in its orbit around the sun. When it does return, it is almost 6 hours later in the day from year to year, so that every fourth year we would begin the year a whole day early if we didn't put in February 29 to compensate.

The fact is that the rotation of the earth on its axis and its revolution about the sun are quite independent of each other. As the sun loses mass by radiating energy and the rotation of the earth slows down because of tidal friction, we may expect—in thousands of centuries—that the year will have a different number of days in it.

Our daily life is ordered by the rotation of the earth with respect to the sun. The majority of us sleep at night, work by day, and play a little near the border line. Thus, from the workaday point of view, the dura-

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tion of time from noon till noon would seem to be the logical unit of time. This would be solar time and could be measured by a sundial. But in September such a day would be 22 seconds shorter than the average, and in December it would be 28 seconds longer. That would not do even as a practical matter, for clocks would require continual readjustment. Therefore, the variations are averaged out over the year to give us *mean* solar time, which is the time in everyday use.

But an averaging is only the last resort in standardization. We might better use for a standard some modern pendulum clock, running in vacuum and driven by a so-called slave clock, for it can be far more constant than the earth-sun combination. The astronomers have, however, in the rotation of the earth with respect to the stars, a clock which surpasses all others in reliability. Each such rotation measures a sidereal day, as it is called, of 24 sidereal hours.

If sidereal time is so much better as a measure, then why shouldn't we use it for everyday? Because, as I have said, our daily activities are regulated by the sun and not the stars, astrologers to the contrary notwithstanding. The motion of the earth in its orbit requires that the earth turn about 361° for noon to recur at a given terrestrial point, for in its travel it has left the sun slightly behind, so to speak, and has to

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turn a bit more and face a little backward. That extra degree of rotation takes 4 minutes, so that the sidereal day is about 4 minutes shorter than the mean solar day. The woes of Daylight Saving would be as naught compared to those of the sidereal addict. Setting his sidereal alarm clock for 6 A.M., he would be awakened at 6 A.M. mean solar time on March 21. But day by day, as spring advanced, it would be darker and darker when he rose. By June 21 he would be getting up at midnight—with breakfast still 7 hours away. By September 21 he would sleep through lunch and arise in time for supper. Only when March came around again would he enjoy a brief interval of normal life.

Now I want to turn from the measurement of time, which is what we really have been discussing, to inquire briefly into the nature of time. It is one of the fundamental things of our experience, which we therefore accept on the whole as a matter of course.

We find ourselves in a complicated, changing world of matter and consciousness which has its existence in a framework of space and time. We are conscious of a here and a there, and of a then and a now. What goes on is describable in its simplest and most elementary terms as happening somewhere at some time. Time and space cannot be *explained* in the sense that

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we attempt to find out what they *really* are, because they constitute the reference frame without which nothing else has meaning. I venture to say that we shall come closer to explaining consciousness than we ever shall to explaining space and time.

But we can discover the properties of space and time. We recognize that space has three dimensions, meaning that to fix the position of an object with respect to its environment we must specify three space-things or coordinates. For instance, to locate an airplane we have to know how far north of us it is, how far east, and how high. Time has only one dimension. We have only to know *when* the airplane is in the position already described. Any other arrangement is, I think you will agree, inconceivable.

In one important and definite respect time differs from space. It is a one-way affair. You can go downtown and come back with the loaf of bread you forgot to get, but you cannot go back to New Year's Day to make that resolution you had intended to. Neither can you have Johnnie go back to early this afternoon and *not* eat that green apple which is now distressing him.

Ridiculous? And yet, when we examine the mathematical equations that describe the motions of particles and their interactions with each other, we find

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in them no hint that time points one way. The further pursuit of this inquiry leads, however, to one of the most difficult concepts of science, called entropy, and ends at best in a highly speculative connection between the one-way nature of time and the inevitable and continuous increase of entropy in the universe.

The time magnitudes that we familiarly encounter extend from the $\frac{1}{10}$ second, which is the smallest interval on a stop watch, up to the span of one's life. The flicker of a motion picture driven at the original rate of 16 frames a second represents the smallest time interval directly perceptible as such. Thus, $\frac{1}{16}$ second to some 2 billion seconds is the range of our direct experience of time. But indirectly we can, by means of instruments, extend our experience in one direction to far shorter intervals, and in the other direction, by written records, extend our knowledge to longer periods.

Shorter time intervals of the order of $\frac{1}{1000}$ second can be obtained by direct mechanical means. Motion pictures showing what happens in intervals of $1/10,000$ second have been obtained by using electrical light flashes of that frequency. The limit to observation of single time intervals lies at about one ten-millionth of a second, which is the fastest speed at which an electron beam can be swept across a fluorescent

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screen and still produce light enough to photograph. But beyond this we still think of time of shorter intervals, even though these intervals are strung together in the successive oscillations of a light wave and cannot be separated from each other or subdivided for examination. It is not that we have reached a point beyond which time is not divisible—for rays oscillating one million times faster are known—but that we are in a region where the physical laws of atoms apply, our ordinary large-scale physical laws being a sort of average over larger distances and longer times.

It is no exaggeration to say that in that region time has lost its fundamental quality in the world of experience, because we no longer experience it—not even vicariously through instruments. It is true that we put a t into the mathematical equations, but that need have no more time significance than the pen with which it is written.

THE NATURE OF LIGHTNING

by DR. KARL B. MCEACHRON

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DR. MCEACHRON, a native of Hoosick Falls, New York, attended Ohio Northern University and, later, Purdue University, where he took a graduate degree in electrical engineering. After teaching at Ohio Northern and Purdue, he went to the General Electric Company, in 1922, to supervise research on lightning arresters. Since 1933 he has been Research Engineer in High-voltage Practice in charge of the Company's High-voltage Engineering Laboratory, at Pittsfield, Massachusetts. His investigations of natural lightning and his work with artificial lightning have made him an authority on high-voltage electricity.

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SINCE the time of Benjamin Franklin, it has been known that lightning is electricity—the same kind that is produced when you rub a cat's fur on a dry day, so-called static, or frictional, electricity. Static electricity is no different from any other kind, but it is called frictional because it is frequently obtained by friction between certain nonconductors of electricity.

Under proper conditions of humidity and temperature, the frictional action of air currents causes a separation of electric charges on drops of condensed

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moisture. The droplets unite and fall; they are again broken up and raised to higher regions by rising air currents. The electrical potentials become higher and higher, and at last a lightning discharge takes place, either to another cloud or to the ground.

Why does lightning want to go to the earth? Because, as the lower portion of the cloud becomes charged to one potential, a charge of opposite potential is induced on the earth beneath. When the potential, or voltage, at the cloud becomes high enough, a streamer begins to form. It progresses toward the earth in a series of starts and stops. In some cases, it takes as long as $\frac{1}{100}$ second to reach the earth. It is not visible to the eye because, along the same path and immediately following the contact of the streamer with the earth, the brilliant lightning flash, which we see, builds up from the ground. This flash travels *from the ground toward the cloud* at a rate of about 18,000 miles a second.

Interesting things are happening on the ground while the streamer is approaching. The streamer carries with it electric charges of the same sign as the cloud from which it came. Therefore, on the earth, directly under the end of the streamer, there is an intensification of charge. This concentration of charge, at the surface of the earth, may be sufficient to produce

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streamers rising upward from the earth. I have a photograph of streamers 4 to 8 feet long extending upward from a beach which was struck by lightning.

Many lightning strokes are multiple in character. They are made up of successive discharges which follow the initial discharge over substantially the same path. It is possible to photograph these successive discharges by using either a moving camera or a moving film. This principle has been used by many observers; a variety of cameras have been built, and they have yielded valuable information on the mechanism of lightning.

High-speed-camera photographs indicate that all but the first of a series of discharges will have a leader stroke, which proceeds from the cloud to the earth without hesitating. As many as 40 of these successive discharges have been reported in less than a second, while 8 to 10 are quite common.

Lightning often strikes electric transmission towers and lines. Formerly, this usually caused interruptions to electric service. But as the result of studies of lightning, means are now available for preventing these interruptions, and service is seldom seriously disturbed. Since engineers are interested in the values of current and potential found on transmission lines as the result of lightning strokes, many measuring

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instruments have been connected to transmission towers and lines to learn more about lightning. As a result, it is now known that the currents to be expected from lightning may be as great as 200,000 amperes, or as little as 5000 amperes. The voltage has been variously estimated from 100 million to 10 billion volts.

The question is often asked: Why does lightning not follow the field of force between the cloud and the earth? If it did, in general it would take a smooth curved path. The answer is that lightning follows the path of least resistance, which it determines for itself as it progresses. One might compare the situation with that which a schoolboy faces when the bell rings after recess and the yard is filled with children. He is on his way to the door, but the path of least resistance may not be a straight line to the door. So it is with lightning—the path is determined by local ionization conditions just ahead of the progressing streamer. In fact, in one investigation, we photographed lightning which came within a few hundred feet of the earth and then changed its course and more or less paralleled the surface of the earth for nearly 2 miles.

Sometimes multiple strokes are very close together. The shortest time of which I have a record is 700

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millionths of a second. A millionth of a second is hard to visualize. An object moving at the great speed of 1000 miles an hour would not move as much as $\frac{1}{16}$ inch in a millionth of a second. So when we say, "as quick as a flash," it is really pretty fast. Individual discharges may rise to crest current in from five to ten millionths of a second, but the duration of a series of discharges may be quite long—as much as a second.

The electric energy in a single lightning flash is really quite small. It would not make many slices of toast in your toaster. But the power, or the *rate* of dissipation of energy, may be enormous because of the short time during which the flash occurs. For illustration, in our laboratory in Pittsfield, Massachusetts, we have an impulse or lightning generator which produces a 10 million-volt flash, 30 feet long, with a current of approximately 25,000 amperes. The total energy is 125,000 watt-seconds. Translated into terms more familiar—that of our electric light bill—this energy is equivalent to a little more than three one-hundredths of a kilowatt-hour which, at a rate of 5 cents, is less than two-tenths of a cent's worth.

However, when it is considered that the discharge is completed in about 10 millionths of a second, the *rate* of delivering energy (the power) is about 12,500,000

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kilowatts. This is about the average kilowatt load of all the power systems of the United States for the month of June.

Natural lightning will frequently have a kilowatt output many times that of our apparatus. It is easy, then, to understand the damage done by lightning. The forces involved may be very great, though the time of application is extremely short.

Much has been said and written about the queer pranks of lightning. To understand these it is necessary to consider for a moment the flow of electricity both through the air as a spark, and through conductors. It has been known for many years that mechanical pressure appears around a rapid discharge in air. This effect is nicely illustrated by passing our laboratory discharge through the small hole in a thick-walled glass or porcelain tube. The pressure evolved with high current will destroy the tube just as though an explosive had been set off in it. This pressure effect produces the thunder that we hear.

On the other hand, if the high-current discharge is sent through a conductor, the magnetic forces set up within the conductor may crush it. Thin-walled metal tubes, and flat strips of copper, have been crushed in the laboratory in this manner. If the conductor is too small to carry the current, it may be vaporized. The

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largest conductor melted by a lightning discharge of which I have a record is an iron conductor slightly more than $\frac{1}{8}$ inch in diameter.

When wood is struck, a certain amount of the wood is turned into vapor, which adds to the pressure created by the spark inside the wood. Trees sometimes explode very violently when struck, scattering debris over a large area. This is one of the good reasons why being under a tree during a lightning storm is likely to be dangerous.

Buildings are frequently struck, but if they are of steel-frame construction, with metal parts projecting from the top, no harm is done. When wood or brick buildings are struck, the damage at times is very considerable. However, lightning-rod systems, properly installed, are very efficient in protecting houses and trees from the effects of lightning.

Electric transmission systems use a modified lightning rod in the form of an overhead ground wire, strung over the conductors and connected to ground at each tower. The spacing from the live power conductors in midspan must be sufficient so that while the lightning is traveling along the ground wire to the near-by towers, flashover will not take place to the power conductors. A similar scheme is also used for the protection of oil storage tanks.

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You may have noticed sometimes a statement in the newspaper to the effect that lightning struck a concrete highway, ripping it up at several points some distance away from the point struck. This effect is due, of course, to the lack of continuity of the metal reinforcing the concrete. Where the electrical connection is poor between successive pieces of reinforcing, the concrete punctures, and the ensuing spark blows a hole in the surface of the road.

As you understand lightning better, your fear of it largely disappears, especially if you can bring yourself to find a point of vantage and watch the storm. Many of the discharges are between clouds, and although these produce the same thunder as discharges to ground, they are harmless. High storms will, as a rule, have a greater number of cloud-to-cloud strokes. If you are timid, remember that if you hear the thunder, the lightning did not hit you. In fact, if you see the lightning, it did not hit you. Furthermore, if you remember that the number of fatal accidents from lightning in the United States does not average more than 500 a year, while automobiles yearly kill more than 30,000, then you will not crawl under the bed when the thunder begins to roll. Instead, you will look for a front seat at a wonderful show of nature.

by DR. FRANK R. ELDER

WE ALL know that when the temperature drops below 32° Fahrenheit, it is time to put anti-freeze in our automobile radiators. Most of us know that when water reaches a temperature of 212° Fahrenheit, it boils. But in scientific books we often see temperatures expressed in degrees *centigrade*. And when we read that some laboratory has succeeded in reaching a new low limit of temperature, that temperature is usually expressed in degrees *absolute*. In order to straighten out these apparently confusing temperature scales, we have to get down to fundamentals. Just what do we mean by temperature?

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Our simplest idea of the meaning of temperature comes through the sense of feeling. We can feel that one body is cold, or that one body is hotter than another. If we take several pieces of the same material, at different temperatures, we can arrange them in order, so that each one is hotter than all that precede it, and colder than all that come after it. This scale of hotness or coldness is really a scale of temperature. The idea of temperature, like the idea of length, is one of the fundamental ideas of nature, and by it we can describe natural phenomena.

But we still have to obtain a standard scale, or measuring stick of temperature. And the instrument with which we are most familiar is the thermometer. A fluid thermometer is a glass tube partly filled with liquid. The liquid expands when it gets hotter; it then fills more of the tube—that is, the upper edge of the liquid column climbs up the tube. When the liquid gets colder, it contracts—takes up less room—and the level falls in the tube. We could put a scale of inches beside the tube and have a temperature scale, of a kind, for that particular thermometer. But what is needed, of course, is a scale for all thermometers on which a certain reading will always mean a certain definite temperature.

The Marks on Your Thermometer

Our ordinary thermometer, for use around the house, has a Fahrenheit scale. It was devised by Daniel Gabriel Fahrenheit, a renowned German instrument maker who lived between 1686 and 1736. Ever since his scale began to be generally accepted, people have wondered why he chose 32° as the freezing point of water, and 212° as the boiling point. They are fairly inconvenient numbers to use.

Recently, fresh light has been thrown on the problem by the discovery, in the Military Academy at Leningrad, of letters sent by Fahrenheit to Boerhaave between 1718 and 1729. These letters show that, actually, Fahrenheit did not pick 32 and 212 as the freezing and boiling points of water. These temperatures were incidental to two other fixed points. The zero was obtained by immersing a thermometer in a mixture of snow and sal ammoniac. The upper calibration point was the temperature of the human blood, which in those days was supposed to be strictly constant for a healthy person, and to which Fahrenheit gave the arbitrary figure of 96. Fahrenheit gave no reasons for adopting 96 degrees as blood heat. He may have chosen the figure because it was divisible by multiples of 2 and 3, and therefore by 12. The decimal system was not in general scientific use in

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his time, while the duodecimal system—based on multiples of 12—was used.

Today we retain the Fahrenheit scale, but it is a slightly different scale from the one devised by its inventor. The fixed points for calibration are deliberately chosen as 32 for the freezing point of water, and 212 for the boiling point. And on this basis blood heat, as we all know, comes out to be 98.6° .

A French scientist, René de Réaumur, showed by experiment that various mixtures of water and alcohol have different expansions. For simplicity he chose a mixture that gave an expansion of 80 parts between melting ice and boiling water. You may occasionally come across European thermometers which are marked in degrees R—for Réaumur—and which give the temperature of boiling water as 80.

In 1736 Celsius, who favored a decimal system—that is, a system of measurement based on the number 10—divided his thermometer scale into 100 parts. This produced the centigrade scale, the one now used in most scientific work.

We have now discussed most of the common thermometer scales, and have seen how they were developed; but there is one more. In the laboratory and in industry very wide ranges of temperature are encountered, and suitable means must be found to

The Marks on Your Thermometer

measure these high and low temperatures. Obviously, any property of matter that varies in a regular manner with temperature may be made the basis of a temperature scale.

Early experiments by Boyle showed that if a definite mass of gas be compressed, doubling the pressure on it reduces the volume of the gas to half. Four times the pressure reduces the volume to one-fourth. In other words, multiplying the pressure and volume together always gives the same value for the product. Actually, exact experiments with different gases later showed that all known gases deviate from this law, particularly at low temperatures and at high pressures. But the relation was so useful that, for convenience, a perfect gas was imagined which obeyed Boyle's Law completely.

Now, when a mass of gas, held at a constant pressure, is cooled, the volume of the gas decreases. This can be demonstrated by blowing up a balloon with air and then pouring liquid air over it. As the gas inside is cooled, it shrinks in volume and the balloon becomes smaller. In this experiment the pressure outside is held approximately the same, because it is the pressure of the atmosphere.

The expansion and contraction of a perfect, ideal gas, then, may be made the basis of temperature

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measurement. Let's take a known volume of some real gas, at 0° centigrade, and measure the volume changes as we change its temperature. Such experiments show us that the volume of the gas increases $\frac{1}{273}$ of its 0° centigrade volume for each degree centigrade rise in temperature. And going the other way, the volume of the gas decreases $\frac{1}{273}$ of its original volume for each degree centigrade drop in temperature. If this is true, and experiment shows that it is, we can cool the gas *only 273 degrees* below zero centigrade. At that temperature the gas will exert no pressure; the gas atoms or molecules will be packed tightly together, with no voids or spaces between them. We cannot imagine any lower temperature. Therefore 273 degrees below zero centigrade is called the absolute zero of temperature. And the temperature scale based on these experimental results is called the absolute centigrade, or the Kelvin scale. On this scale, 0 is the absolute zero of temperature; the freezing point of water is 273° absolute; the boiling point of water is 373° absolute. Each degree of this scale represents the same temperature change as does each degree on the centigrade scale—the difference between the two scales is merely that of locating the scale zero.

The Marks on Your Thermometer

You understand that no *real* gas actually behaves as does Lord Kelvin's ideal or perfect gas. All gases have ceased to be gases at absolute zero. They turn to liquids and then to solids before they reach the zero of the Kelvin scale. Hence, gas thermometers cannot be used to measure such low temperatures, and other methods must be devised.

There are such other methods. Changes in electrical resistance are used to measure both very low and reasonably high temperatures. Optical methods, depending on the light from incandescent bodies, are used for very high temperatures. But the instruments using these principles are all calibrated in terms of one or the other of the conventional temperature scales that we have been discussing.

METEORITES

by EDWARD S. C. SMITH



PROFESSOR SMITH was born in Biddeford, Maine, and was graduated from Bowdoin College, going to Harvard University for his graduate study. He joined the faculty of Union College in 1923, where he is Professor of Geology and head of the Department of Geology. He has contributed many articles to scientific journals, has been President of the New York State Geological Association, and is an authority on the geology of the State of Maine, where much of his research has been carried on.



IF YOU look up into the heavens on any clear moonless night you may see a point of light flash through the sky and disappear. It is as though one of the stars had fallen from its position and been blotted out in the depths of space. Such a phenomenon is commonly called a "shooting star"; but it is not a star, but a relatively small chunk of matter that has entered our atmosphere at a speed of anywhere from 10 to 50 miles a second. This velocity produces enough friction to raise such bodies to incandescence, so that most of them are burned up completely at heights of about 75 miles. Some of them, however, survive this passage through the atmosphere and reach the surface of the

Meteorites

earth. Those that are consumed before reaching the earth's surface are called meteors; those that arrive at the earth's surface are called meteorites.

All meteorites may be placed in three classes—those that are chiefly an iron and nickel alloy, those that carry metallic and stony material in about equal proportions, and those that are chiefly stony. The metallic meteorites often contain cobalt; some contain platinum. Of the total number of meteorites known, the stony are in the majority.

No new elements have been discovered in meteorites, but many compounds have been found that do not occur naturally on the earth. Such a one is lawrenceite—chemically a chloride of iron. The presence of this substance in a meteorite is proof that it came from a place devoid of oxygen, for in contact with oxygen this chloride turns very readily into an oxide. Hence, lawrenceite will cause the discoloration or even the disintegration of a meteorite containing it, when exposed to our atmosphere.

On the other hand, there are many minerals present in meteorites that are familiar ones, such as apatite, the feldspars, olivine, pyroxene, quartz, and even diamonds. The metallic meteorites often show a curious crystallization of their constituents that is quite unknown terrestrially.

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We are interested in these objects that fall from the sky chiefly because they are the only tangible clues to the kind of matter which makes up the universe beyond our own little chunk of matter, the earth.

By means of the spectroscope, astronomers can tell us what elements occur in the outer layers of the stars, but meteorites can be handled, examined, and tested in various ways; their messages are not transmitted through millions of millions of miles of space by light waves, but are, so to speak, delivered in person. Some of these messengers come from our own solar system, for revolving around the sun are unnumbered bits of matter, from the size of dust to bodies weighing many tons. We are, therefore, constantly being bombarded with extraterrestrial matter.

But the high velocity of many meteors is proof that they do not originate in the solar system. They come from the depths of interstellar space. It has been estimated that several million meteors enter our atmosphere each day—a stupendous heavenly barrage, of which we are scarcely aware. Meteors usually become luminous at altitudes of about 60 to 100 miles above the earth. Rarely do they become so highly incandescent as to be visible in the daytime. One of these daylight meteors passed over New England several years ago, but it appeared to fall in the ocean.

Meteorites

The question is often raised: "If the earth is being struck by so many of these missiles, has anyone ever been killed or injured by them?" So far as is positively known, no one has either been killed or injured. A 40-pound meteorite crashed through a house in Bohemia in 1847, showering the residents with plaster and other debris but injuring no one. In the Field Museum at Chicago there is a small meteorite that plunged through the roof of a barn and embedded itself in the floor. Such examples of buildings being struck are exceedingly rare.

The time before sunrise is, in general, the most favorable for the observation of meteors. Then we are in the position of being "head on" in our passage through space, and the earth is catching up with the slower meteors that may be moving in the same direction as the earth and in its path, or it is meeting those moving in the opposite direction.

The favorable time for the arrival of meteorites seems to be late in the afternoon and early in the evening. The earth has then turned 180 degrees on its axis, and any meteors that enter the earth's atmosphere are those that are catching up from behind. Their velocities may be little greater than that of the earth itself, so they are less liable to be consumed in their earthward flight. Their speeds have been esti-

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mated to be as low as 2 or 3 miles a second. In contrast, morning meteors may travel as fast as 50 miles a second.

While it is true that most of the "shooting stars" are burned up, yet their substance in the form of oxide is added to the atmosphere and gradually settles to the surface of the earth. In this way thousands of tons of matter in the form of meteoric dust are added to our planet daily. Yet this amount, great as it may seem, is really almost negligible when the tremendous surface of the earth is considered.

Probably the largest known meteorite lies embedded in the ground in southwest Africa. This is the recently discovered Hoba iron, whose weight is approximately 60 tons. There are, however, in three widely separated regions, evidences of catastrophic impacts of much larger meteorites. The best known is probably the famous Meteor Crater near Winslow, Arizona. Here, on the flat desert lands, is a depression 3 miles in circumference and nearly 600 feet deep, around which have been recovered about 16 tons of metallic meteorites. The crater is formed in a great thickness of sedimentary rocks, principally sandstones and limestones, some of which have been rendered highly porous—presumably as the result of a terrific explosion.

Meteorites

At Henbury, central Australia, is a group of much smaller meteor craters, the largest of which is about 220 yards across and about 60 feet deep. Many meteorite fragments have been recovered from that locality.

A third group of craters, as yet inadequately described, lies in north-central Siberia. Doubtless these also were caused by the fall of a swarm of meteorites rather than by a single large one. It is not pleasant to contemplate the damage and loss of life that would be incident to such a swarm of meteorites striking a large city. But the odds against such an occurrence are very great indeed.

While meteors are likely to be seen almost any time, there are periodic recurrences of so-called meteor "showers," during which the number of meteors seen in a given unit of time is much greater than usual. In fact, it is probable that the awakening of the modern interest in meteors and meteorites began with the great meteor shower that occurred early in the morning of November 12, 1833, when, according to all accounts of it, the "sky presented a remarkable exhibition of fireballs, commonly called shooting stars."

The phenomenon was further described as "striking and splendid," and the "flashes of light were so bright

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as to awaken people in their beds.” These meteors seemed to radiate from a point in the direction of the constellation Leo, and have been called the Leonids. This shower was widely observed and recalled a similar one on November 11, 1799. This led to the belief that the swarms of meteors moved in a definite orbit such that they would reappear every 33 years. They did come again in 1867 according to schedule, and should have appeared in 1899 or 1900, and again in 1933 or 1934, but on both of the later occasions the meteoric displays were highly disappointing. It seems more than likely that the attraction of the great planet Jupiter has disturbed the normal paths of these swarms of meteorites, so that for some years at least the earth will not pass through the main body of them.

The study of meteors and meteorites is a fascinating one, but quite aside from their mere spectacular phases we may hope to gain from them valuable information concerning not only the solar system but the universe itself.

ANIMAL LIGHT

by DR. LEWIS R. KOLLER

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DR. KOLLER, born in New York City, studied at Cornell University, where he received his Doctor of Philosophy degree. From 1917 to 1919 he was a Civilian Radio Engineer of the U. S. Army Signal Corps. Later he taught physics at Cornell, joining the General Electric Company, as physicist, in 1922. Since 1925 he has been a member of the Research Laboratory staff. His *Physics of Electron Tubes* was published by the McGraw-Hill Book Company in 1934.

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ON SUMMER evenings the glow of the firefly is a common sight. Few persons can observe it without wanting to know more about it. Sunlight and firelight, incandescent and arc light are taken for granted. But there is something different about the glow of the firefly. Perhaps it is because it lacks the accompaniments that we usually associate with light. There is no heat, no noise, no wiring, no switch. Yet if we study the light of the firefly, we find that, essentially, it is very much the same as other kinds of light. It can be reflected, refracted, polarized, and it has all the other attributes of ordinary light. Its chief

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distinguishing characteristic is that very little heat is produced with it. This kind of light production without heat, sometimes known as "cold light," is called *luminescence*.

The firefly—and by the way, it is not a fly but a beetle—is by no means the only living source of light, although perhaps it is the most familiar one. There are altogether about 40 different orders (as the zoologist calls them) of living things that produce light. They include members of both the animal and vegetable kingdoms, but strangely enough, they are all either terrestrial or marine forms of life. No fresh-water forms are luminous.

The only light-producing plants are two groups that many of us perhaps do not think of as plants—the fungi and the bacteria. The part of a fungus that we ordinarily see is the "fruit body," but the fungi possess also a network of threads called the *mycelium*. It is, for the most part, the mycelium rather than the fruit bodies that shows luminosity. The mycelium is usually underground or concealed in decaying wood or under the bark of a rotting tree stump. For this reason luminosity is often observed when the bark is removed from a decaying log or when the log itself is shattered. This is sometimes called "fox fire."

Animal Light

Many kinds of bacteria give off light, particularly those that are found on decaying meat or decaying fish along the seashore.

The light-producing power is more widely distributed among animals than among plants. The so-called phosphorescence of sea water is caused by several forms of protozoa. These tiny single-celled organisms are often present in numbers sufficient to color the sea pink by day.

Many forms of jellyfish show luminosity. So do the echinoderms, which include the brittle sea stars; the cephalopods, which include the squids and many marine worms; the crustaceans, the insects, and at the top of the scale, the fishes. Several kinds of sharks are luminous. All of these are inhabitants of salt water. But luminosity is by no means confined to creatures living in the depths of the sea, for many of them live in shallow water or at the surface or near the shore.

Many insects are luminous and so, often, are their larval forms and even their eggs. The best known of these is the firefly or lightning bug, and its larval form, the glowworm. Reports have been received of luminosity in higher animals, but these have always been found to be due to fungi or bacteria which have been taken as food or which have in some way established themselves in or on the body.

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The production of light by living organisms is not really a vital process. The plant or animal simply manufactures a chemical that is capable of producing light. This substance can be extracted and made to produce light apart from the body of the living creature that manufactured it. So far, however, it has not been possible to make these chemicals synthetically; the secret belongs only to the animal.

The light-producing substance is called *luciferin*. Luciferin produces light only when it combines with oxygen and forms a new compound, called *oxiluciferin*. Hence, without air or oxygen, no luminescence can take place. The luciferin cannot combine with oxygen, however, unless there is present another chemical, called *luciferase*, which also is manufactured by the animal. This substance acts as an enzyme or catalyst which encourages the oxidation reaction. Both of these substances can be extracted from the luminous organs and be made to produce light when mixed in a test tube. The combination of oxygen and luciferin produces a disturbance of the electrons of the molecules that results in light. The color of the light produced depends upon the luciferase, while its brightness depends upon the speed with which the reaction takes place. A remarkable feature of the chemistry of light-producing animals is that the luci-

Animal Light

ferin, after being oxidized, is reduced again by the animal and thus is used repeatedly.

In some animals the light-producing materials, that is, the luciferin and luciferase, are secreted in a slime on the body or are ejected into the surrounding water. Thus they give rise to luminosity outside the animal. More often, however, as in the case of the firefly, the light is produced in highly specialized light organs or lamps within the body. These have some remarkable engineering features. The light organs are usually symmetrically placed on either side and underneath the animal and throw the light down. In general, they consist of a transparent layer of skin under which is a layer of cells containing the light-producing matter. Behind these is a layer of reflector cells, which project the light outward. In some fishes there is even a layer of cells serving as lenses. Since oxygen is necessary for the production of the light, the cells have a highly developed system of tubes for supplying it.

Some forms, such as the bacteria and fungi, glow continuously. Others emit light only when stimulated from outside, as for instance when a boat sends a wave through sea water. Some of the fishes have a screen, similar to an eyelid, by means of which the light can be shut off, while still other forms can control the

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light-producing mechanism itself. Just how this is accomplished is not yet understood.

The spectrum of animal light is neither a line nor a continuous spectrum. It consists of a broad band of blue-green or yellow-green light with practically no measurable ultraviolet or infrared radiation. The term "cold light" which has been applied to it has given rise to the belief that the animal's way of producing light is unusually efficient. This is not really the case. The production of animal light is a by-product of the chemical reaction that takes place when luciferin is oxidized. Some work done by Professor E. N. Harvey, of Princeton University, makes it possible to estimate the efficiency of this reaction. His results show that luminous bacteria are just about as efficient in converting energy into light as are ordinary incandescent lamps. It is true that the radiation produced by these organisms is all in the region of the spectrum to which the human eye is most sensitive, but only a small part of the energy of the chemical reaction goes into light production. It would take about 1500 fireflies to produce a one-candlepower light.

The light production for a given weight of luciferin is relatively small—about $\frac{1}{65}$ as much as we could get by burning the same weight of a paraffin candle, or

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$\frac{1}{287}$ as much as we would get from the same weight of acetylene.

Just what purpose luminosity serves in nature is not definitely known. In a few instances it is associated with mating; in some cases it may aid the animal in procuring food or it may be a means of protection. But for the most part, its purpose is obscure.

EARS, HUMAN AND ELECTRIC

by ALBERT J. MUCHOW

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MR. MUCHOW is a native of Hartford, South Dakota. After graduating in Electrical Engineering from the University of South Dakota, he joined the General Electric Company and was from 1929 to 1937 a member of the staff of the General Engineering Laboratory, studying problems of sound measurement. Since 1937 he has been with the Warren Telechron Company.

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WHAT we mean by "sound" depends upon the definition we choose. We may define sound as the sensation perceived when the auditory nerves are stimulated. Or, like most scientists, we may use the word to designate the external physical disturbances that are capable of affecting the ear, even though there is no ear to hear. Thus the old dispute about the bell ringing in the desert boils down to a matter of definition of terms.

Man's first experiments with sound are hidden far back in human history. Some of the most primitive races have left records to show that they used musical instruments. The art of producing pleasant sounds—called music—developed to a high degree without

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much aid from the physical sciences. Aristotle, several centuries before the Christian Era, used vibrating strings to investigate the simple mathematical relations that exist between harmonious sounds.

Galileo, during the sixteenth century, rediscovered Aristotle's theories and reached the conclusion that sound is associated with minute vibrations in air. In 1705 an English physicist demonstrated the correctness of Galileo's concept by showing that sound could not be transmitted through a vacuum where air does not exist to serve as a medium of transmission. At about the same time, a French mathematician demonstrated the relationship between the pitch and the rapidity of vibration of a sounding body. After this, the discovery of the fundamental principles of sound came thick and fast.

Even superficial observation will discover that sound is closely connected with the vibration of a sounding body. A bell is struck. You hear the sound, and at the same time, by touching the bell, you can feel the vibration. As the bell vibrates, it imparts a similar vibratory motion to the air particles close to the bell. The motion of these air particles is rapidly passed on to those a little farther off. By a continuation and extension of this process, the vibrating motion of the bell sets all the surrounding air into vibration.

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If we were able to see the particles of air in action while excited by sound, we would notice that while each particle makes only a very short excursion to and fro, yet the disturbance moves outward from the source at a speed of about 1100 feet a second. (This corresponds to about 750 miles an hour.) The distance any individual air particle travels to and fro depends upon the intensity of the sound. In a moderately loud sound, this distance may be only one and one-half *millionths* of an inch!

With even the loudest common sounds, the acoustic power generated by the source is usually very small. It has been estimated that if the entire population of the United States were to talk in a normal conversational tone, the total power converted into sound would be only about equal to that required to operate a 100-watt incandescent lamp. Electrically, we can get the equivalent power in our homes at a cost of less than a cent an hour!

The quality of a sound depends upon the number, the relative intensity, and the pitches of the various tones present. Most sounds contain a variety of tones. You may have noticed how the echo of a shout directed at a cluster of trees sometimes returns to you with a characteristic pitch higher than that of the shout. The phenomenon may be explained by

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selective reflection of the sound, and is known as a harmonic echo. The lower pitched components of the shout may pass through the grove without being appreciably reflected; the higher pitched components are quite readily reflected and return to the listener to produce an altered quality.

Many interesting phenomena associated with sound—such as reverberation in rooms, the roll of thunder, the passage of sound through speaking tubes, echoes, whispering galleries, harmonic echoes—are the result of the reflection of sound waves. Even the mythical “ocean’s roar” that one hears in a sea shell or a glass tumbler can be explained by sound reflection. The transmission of sound for long distances through speaking tubes, railroad rails, and metal rods is made possible by internal reflections at the boundaries, so that the sound is confined.

This spreading of sound by internal reflections through connecting metallic parts of a machine or through the steel and concrete portions of a building leads often to difficulties in locating a disturbance. What sounds like a rattle in an automobile steering wheel may be a loose connection near the front wheel. And a hum or rumble audible on the top floor of an apartment building may originate in machinery in the cellar.

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Having considered a few of the properties of sound, let us turn our attention to the method by which we hear. When sound waves in air strike the ear, they are conducted into the external auditory canal and strike upon the tympanic membrane, or eardrum, which seals the inner end of the canal. The eardrum is set in vibration by the impinging sound waves. These vibrations are in turn transmitted with decreased amplitude but increased pressure by a group of three small bones—the so-called hammer, anvil, and stirrup—which act like a chain of levers to vibrate the fluid contained in the canal of the inner ear. This canal, or labyrinth, is coiled into a small spiral of $2\frac{3}{4}$ turns and contains a central membrane, in which the auditory nerves terminate.

The vibrations excited in the fluid of the inner ear stimulate nerves in various regions of the membrane. The length of the central, or basilar membrane is about $1\frac{1}{8}$ inches, and its greatest cross-sectional area is less than five ten-thousandths of a square inch. These dimensions are startling when we consider that sounds ranging a thousandfold in frequency and 1000 billionfold in intensity are heard and differentiated by this small but important part of the ear.

The human ear is capable of hearing only those sounds that fall within certain pitch and intensity

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limits. Tests have shown that the lowest pitch that the average ear can hear is about 16 vibrations a second, and the highest 16,000 a second. This range corresponds to that from the deepest note on a pipe organ to a note about six octaves above middle C. We are probably very fortunate to have our hearing limited in this way. Microphones coupled to suitable amplifiers indicate that many sounds exist in nature that we can never hear directly because of their high pitch. It is said that during the World War police dogs were often secretly called by means of high-pitched whistles that humans could not hear. It has been demonstrated that many insects produce intense sounds at high frequencies beyond our hearing range. If our ears were as sensitive to sounds up to 25,000 vibrations a second as they are to tones an octave above middle C, we should undoubtedly consider the sound produced by a dog walking through grass very intense. A cricket's chirp would sound quite different, because we should be able to hear overtones or harmonics that our ears now fail to catch.

In order for sound to be audible, it must possess enough power to stimulate the auditory nerves. The amount of power required depends somewhat upon the pitch of the sound. The ear is most sensitive to

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sounds having a frequency between one and four octaves above middle C.

The very properties of the ear which enable it to hear feeble sounds and yet avoid damage when listening to very loud sounds render it unreliable as a measuring device. Its memory regarding the intensity is very poor, and it is quite unable to determine the pitch of the various tones present in sound. Moreover, individuals differ greatly among themselves in their judgment of loudness and in their reactions to various types of sound. These shortcomings of the human ear have created a demand among investigators for instruments that would measure sound and give results commensurate with, or related to, the sensations of loudness perceived by the ear.

Within recent years the development of sensitive microphones and vacuum-tube amplifiers has made possible devices that are particularly adapted to serve as "electric ears" for noise-measurement purposes. The essential parts of an "electric ear," or a sound meter, are a microphone to convert the sound vibration into electric voltage variations, an ear-weighting network to provide a response similar to that of the human ear, and an amplifier fitted with an indicating instrument to measure the intensity of the sound.

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Such sound-measuring instruments are generally portable and provide a means whereby a large number of measurements may be taken in a short time with the assurance that the readings may be accurately repeated whenever desired. The results are given in units called decibels, which are a measure of sound in much the same way that degrees Fahrenheit are a measure of temperature.

The feeblest sound that we can hear has a value of about zero decibels; the loudest about 120 decibels. The noise in a quiet country residence averages about 30 decibels, in a quiet street 50 decibels, in an automobile at 40 miles an hour 70 decibels, and in a subway car about 90 decibels. The scale chosen is such that each increase of 10 decibels corresponds to a 1000 per cent increase in the intensity of the sound. A sound of 120 decibels has an intensity one million million times as great as a sound of zero decibels. Expressing this tremendous range in another way, we can say that the intensity of the feeblest sound we can hear is to the loudest as one second of time is to a million years!

These new instruments and standards for measuring noise are being employed to determine what levels of noise the public regards as acceptable, or comfortable, for all sorts of living conditions—in homes, offices,

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workshops, and streets. They enable equipment manufacturers and others concerned with promoting quiet living conditions to specify by one system the noise levels produced by apparatus. They have been of great value in making possible a scientific approach to the many problems encountered in locating and controlling unpleasant noises that emanate from various types of machinery. While this so-called "electric ear" in no way enhances our hearing or appreciation of a symphony or a bird song, it is helping us to obtain a more complete understanding of the nature of noise, and to achieve the desirable goal of comfortable quietness.

VACUUM

by EDWARD F. HENNELLY

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MR. HENNELLY, a native of Johnstown, New York, is a graduate of Union College. During the World War he was engaged in submarine-detection work. Since 1912 he has been a member of the staff of the General Electric Research Laboratory, where his investigations of chemical and physical problems have often involved the use of special high-vacuum techniques.

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AN ABSOLUTE vacuum is—or would be—a portion of space entirely free from matter. Man, however, has been unable, with the most refined chemical and physical means of exhaust, to remove every trace of matter from any portion of space, even the smallest. For example, when a glass bulb, 5 inches in diameter, has been made as empty as possible, it still contains several million million gas molecules, although the pressure within it has been reduced to less than one thousand-millionth of an atmosphere.

The word “atmosphere” suggests the envelope of gas which surrounds the earth, and if we review some of the facts that are known about the earth’s atmosphere, we shall be in a position to compare what

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man has been able to accomplish in producing a vacuum with the vacuum which may be found in nature.

The earth's atmosphere is, in the main, a mixture of two gases, nitrogen and oxygen. At the earth's surface a cubic centimeter of space—which is the volume of an ordinary marble—contains about a million million million gas molecules. As we go to higher levels of the atmosphere, we find the molecular crowding less as the distance from the earth increases. At a height variously estimated at 100 to 500 miles, the atmosphere would be practically nonexistent; that is, the condition would be found which corresponds to our original definition of a vacuum—empty space.

These 500 miles, taking the maximum estimate, are, of course, insignificant compared with the distances used to measure the spaces between the stars, or even those in our own solar system. To avoid the use of the tremendously large numbers that measure these great spaces, let us consider a smaller physical scale.

Imagine you have before you a small table-size globe representing the earth—one about 8 inches in diameter. This would make a convenient reference scale, since 1 inch would be about 1000 miles. The

Vacuum

earth's atmosphere, using our estimate of 500 miles, could now be imagined as a gaseous envelope $\frac{1}{2}$ inch thick surrounding the surface of the 8-inch globe. The moon, on this scale, would be a sphere about like a tennis ball at a distance of 20 feet. Except for the thin layer of gas surrounding the earth, all the space between the two spheres would be empty.

If we wished to add the sun to this scale, it would be a sphere between 70 and 75 feet in diameter and about a mile and a half away, and again, except for the sun's atmosphere, all the space between earth and sun would be empty. Finally, beyond our solar system, the regions between the stars add to the immensity of this empty space, leading to the estimate that, if all the matter in the universe were evenly distributed throughout space, there probably would not be a molecule of gas in 10 cubic centimeters.

It might be thought, then, that a nearly perfect vacuum could be obtained by enclosing some portion of this empty space within a glass bulb. If such a fanciful operation were possible, we should be defeated in our attempt. All samples of matter that we can obtain on earth have, since the beginning of time, been saturated with volatile gases, and these gases would continue to evolve indefinitely. So in our experiment, the very walls of glass intended to exclude

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stray molecules of gas would themselves be sources of other gas, spoiling our sample of interstellar vacuum.

Now to come back to earth. The history of science records that more than 2500 years ago the Greek philosophers discussed the nature of a perfect vacuum, but they, like their followers and successors for hundreds of years, were satisfied with discussions and very little concerned with tests and experiments.

The name of Torricelli is associated with the early experimental period of physical science. He filled a glass tube, closed at one end, with mercury, and then arranged that the open end was beneath the surface of more mercury in a dish. He showed that when the glass tube was longer than 30 inches, the mercury column in the tube always sank until its top surface was 30 inches above the surface of the mercury in the dish. The space in the upper end of the tube above the 30-inch level was called the *Torricellian vacuum*, and for a long time it was considered to be the most perfect vacuum possible. We know now, however, that in such a space there still remained mercury vapor, some traces of air, and probably, as was pointed out previously, some gases given off by the glass tube.

Before turning to modern vacuum methods, let us consider one more early experimenter, Otto von

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Guericke, who lived in Magdeburg in the middle seventeenth century. He took two copper hemispheres, about 22 inches in diameter, and fitted them together as tightly as possible with a gasket soaked in wax and oil to make an airtight joint. The air in the resulting sphere was pumped out through a small opening, which was then closed with a tap. He then demonstrated that two teams, each of eight horses, when pulling in opposite directions, were unable to pull the hemispheres apart. Von Guericke knew the explanation of this phenomenon—that, as a result of the vacuum inside them, the hemispheres were held together by the external pressure of the atmosphere. Although the great physicist of Magdeburg carried out this experiment close to three centuries ago, his memory is honored with pageants in his native town even to this day, and the experiment is repeated at each one.

The last 50 years have seen great developments in vacuum technique. Better pumps have been made. More delicate and accurate methods of measuring the degree of vacuum have been discovered, which, if less spectacular, are certainly less cumbersome than the 16-horse method of 200 years ago. These methods have taught us many important things about common materials.

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For example, we now know that glass, as well as other solid materials, is covered with a thin coating of condensed air or of other gases like water vapor, which adheres to the surface like a film of varnish. This film of molecules is so stable at ordinary temperatures that it will not come away rapidly, even in the best vacuum. Yet if the film is not removed during exhaust, it will later leave the surface gradually and spoil the vacuum conditions. So, good modern vacuum technique demands that a glass bulb, for an incandescent lamp or X-ray tube or radio tube, be heated to as high a temperature as possible while being pumped, in order to remove this film.

We have learned, too, that both metal and glass have dissolved in them large amounts of gas which can be removed only by heating in vacuum.

Even after prolonged pumping and heating, however, there may still remain in an evacuated space small amounts of what are called *residual gases*. Purified charcoal, cooled by liquid air, is sometimes used as a sponge to soak up these residual gas molecules and remove them from the space.

Then there are chemical methods for reducing the residual gas pressure in a vacuum tube. These are represented by the practice of evaporating small amounts of special metals, such as calcium and mag-

Vacuum

nesium. These metals condense on the glass wall to give the familiar silver appearance of radio-tube bulbs. Such metals are particularly active in combining with oxygen and with gases containing oxygen, such as water vapor, to form permanent solid compounds.

It is in no sense an admission of failure to note that after these special operations, together with others of a like nature, have been carefully carried out to produce the highest degree of vacuum, there still remain in the best exhausted device as many molecules in a cubic centimeter as there are people on the earth. Instead, it would be more nearly correct to point out that vacuum equipment and technique have developed fast enough to keep well ahead of the requirements of those sciences for which they are, in fact, the tools.

THE RED PLANET MARS

by DR. FREDERICK W. GROVER



DR. GROVER, born in Lynn, Massachusetts, received the degree of S.B. from the Massachusetts Institute of Technology and of M.S. from Wesleyan University. He earned the degree of Doctor of Philosophy at George Washington University and at Ludwig-Maximilian University, Munich, Germany. He has taught physics and astronomy at Wesleyan, has been a volunteer observer of the Harvard Observatory, has been a member of the staff of the U. S. Bureau of Standards, and has taught at Lafayette College and Colby College. Since 1920 he has been a member of the faculty of Union College, where he is Professor of Electrical Engineering. A recognized authority on electrical measurements and inductance, he is the author of some 30 monographs on these subjects. His book on astronomy, *The Pageant of the Heavens*, was published by Longmans, Green & Company in 1937.



TO THE possessor of a small telescope, Mars, although it is the nearest of all the planets except Venus, is a disappointing object. Little more than a tiny orange-red disk can be made out. With a large telescope, permanent darker spots can be seen, and their shapes were long ago mapped. A few hours watching makes it evident that these dark areas drift

The Red Planet Mars

across the disk, and it is possible to determine that Mars makes one complete revolution on its axis in 24 hours, 37 minutes, and 22 seconds. Therefore, the Martian day is only about half an hour longer than our own. Furthermore, the axis of Mars is inclined to the plane of its orbit by an angle of $23\frac{1}{2}$ degrees, which is the same as the inclination of the earth. This proves that Mars, too, has seasons, although each season is twice as long as ours, because the Martian year is about twice the earth's year.

Anyone who has watched the planets knows that Mars is conspicuously bright for only a few months every other year. This is because the distance between Mars and the earth varies widely. Mars revolves about the sun in an orbit which is, on the average, about half again as far from the sun as is the earth's orbit. It takes almost two of our years for the circuit. Thus, at intervals of two years and two months, the planet approaches as close as about half the distance between the earth and the sun. At times halfway between the dates of closest approach, the distance of the planet reaches a maximum value of about two and one-half times the distance of the earth from the sun. Such wide variations in distance necessarily bring about wide changes in apparent brightness. When Mars is nearest, it approaches Jupiter in bright-

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ness; at its farthest, it is no brighter than the stars in the Big Dipper.

Although Mars has a day about the length of ours and has seasons, there the similarity to conditions on the earth ends. If we could view our earth from Mars, it would appear like a bright star, probably brighter than Jupiter appears to us. Looking at the earth through a telescope, we would probably see the continental outlines, so familiar from our study of geography, but blurred by haze, and extensive areas would always be overlaid by clouds. By contrast, our telescopic views of Mars are usually strikingly free from obscuration or blurring. Sometimes, it is true, small areas of Mars are dimmed by a thin haze, and at times dusky moving spots are seen, which may be dust storms on the planet. These facts suggest that Mars has, at best, a very thin atmosphere and cast doubt on the existence of any considerable water supply.

Mars is a small planet, with only half the diameter of the earth and with only one-tenth its mass. A man weighing 150 pounds on the earth would weigh only 57 pounds on Mars, but any chance of making a record high jump as a result of this favoring circumstance would be offset by the difficulty of breathing in the Martian atmosphere. Our moon, whose diame-

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ter is only one-half that of Mars, has lost *all* her atmosphere and water vapor because of the weakness of her gravitational pull. With Mars the same tendency has been operative, but affairs are not so bad as on the moon. Mars has an atmosphere, although it is probably more tenuous than the atmosphere found at the summits of our highest terrestrial mountains. The spectroscope shows that there is, also, water on Mars. Furthermore, we can see what appear to be polar ice caps on Mars, which melt as the summer advances and form again in the Martian winter. The water available on the planet must, nevertheless, be limited in amount.

Careful measurements of the tiny amounts of heat radiated from different parts of the surface of Mars have been made by Lampland and Coblentz in Arizona and by Pettit and Nicholson at Mount Wilson. These observers find that, in the regions near the center of Mars, the summer day temperatures can reach values as high as 50° or 60° Fahrenheit. The worst feature is that, during the nights, the heat accumulated during the day is radiated away so rapidly that before sunrise the temperature may drop lower than 100° below zero.

Thus the two commodities, air and water, which we take for granted, are scarce on Mars, and the

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Martians, supposing that any exist, must have difficulty in keeping from freezing during the night. And that brings us to the intriguing question whether any evidence exists to indicate that Mars is inhabited.

In 1877, Schiaparelli published observations and drawings of narrow, remarkably straight markings running for hundreds of miles over the planet. As the Martian summer advanced, these were seen to grow more pronounced. Schiaparelli explained these markings as due to vegetation bordering irrigation channels. The straightness of the markings suggests that they are artificial, and if this is so, the further inference that they have been constructed by beings possessed of extraordinary engineering ability.

These observations have been confirmed by certain other astronomers, notably those at the Lowell Observatory, in Arizona. However, other observers studying Mars have seen only ill-defined markings. It has been objected also that such markings are so narrow and so near the limits of visibility, it is not possible to be certain that they are continuous.

The whole subject is very puzzling, and it is difficult to see how certainty can ever be reached. Further, all suggested schemes for signaling Mars with elaborate and extensive arrangements of lights, or by radio waves, assume the possibility that we could make our-

The Red Planet Mars

selves understood. To carry on an interchange of ideas with a race of beings so organized physically as to endure lack of air and water, and the extremes of a perfectly terrible climate—a race, moreover, whose civilization may easily be either vastly more advanced than our own or entirely rudimentary—would seem to be a hopeless undertaking.

However, nothing prevents each one of us from constructing our own mental pictures of conditions on Mars, the while we congratulate ourselves that our lot has been cast on the earth. Distracted though it may be with floods, dust storms, wars, and various forms of human cruelty and strife, our earth offers much better living conditions than does the red planet, Mars.

CHEMICAL REACTIONS IN THE HUMAN BODY

by DR. MURRAY M. SPRUNG

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DR. SPRUNG was born in Wahpeton, North Dakota, and studied at the University of Minnesota, where he received his Doctor of Philosophy degree in chemistry. He has held a National Research Fellowship at Harvard, has taught at the University of Minnesota, and has been a Research Associate at Princeton. In 1933 he joined the General Electric Research Laboratory, where much of his work has been in the field of organic chemistry.

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THE human body, endowed as it may be with a mysterious and wonderful vital force, still obeys the same physical and chemical laws as does ordinary inanimate matter. The changes that occur in the body, most of which are chemical in nature, are thus fundamentally the same as reactions that are conducted (with the aid of human intelligence) in beakers, flasks, or similar chemical apparatus. In fact, many reactions of physiological significance can be duplicated in the laboratory merely by bringing together the proper substances under conditions which approximate the normal environment of the body.

Chemical Reactions in the Human Body

The body itself participates in many of the transformations which occur within its walls. Other chemical changes that occur, however, primarily concern substances added to the body for the purpose of sustaining life. Such substances are, of course, called foods. To understand the chemistry of many of the vital processes, it is necessary to have some knowledge of the chemical nature of foods.

The basic foods are usually classified as proteins, carbohydrates, and fats. However, these basic foods alone will not support life for any length of time. One's diet must contain, in addition, water, essential mineral elements, and certain other substances, which are present in ordinary foodstuffs in relatively minute amounts, known as vitamins.

The human body, in common with most forms of living matter, is largely composed of but four chemical elements—oxygen, carbon, hydrogen, and nitrogen. It is not surprising, therefore, that ordinary foods also consist largely of these four elements. Individual foods, however, differ appreciably in their composition and chemical character.

The proteins, which are present in foods such as eggs, meat, fish, and certain legumes, have been found to contain carbon, hydrogen, nitrogen, and, in some cases, sulphur. They consist of enormously large

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molecules—anywhere from 1000 to 100,000 times as large as simple organic molecules like those of grain alcohol, ether, or chloroform. By experiments carried out in the ordinary manner, in glass or other inert vessels, it is possible to break down protein molecules into consecutively smaller and smaller products. The end products of these transformations are simple nitrogen-containing substances called *amino acids*, which may be considered the fundamental building blocks of protein molecules. About 20 of these building blocks are known. In the gigantic protein molecules large numbers of individual amino acids are strung together in some complex but regular pattern. The exact nature of this pattern is the basis of numerous researches now being carried on throughout the world.

The carbohydrates include the principal energy-producing nutrients, such as those contained in cereals, potatoes, and other starchy vegetables. Sugars are also included in this class. Carbohydrates are made up of three elements only—carbon, hydrogen, and oxygen. Like the proteins, the complex carbohydrates consist of very large molecules—at least 1000 to 10,000 times as large as the molecules of simple organic substances. They also may be broken down into unit building blocks, and when this is done, a single carbo-

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hydrate molecule gives just one simple unit—a sugar. Thus, many starches, as well as cellulose, may be converted completely to the simple sugar, glucose. Other carbohydrates give simple sugars that are similar to, but not identical with, glucose.

The third basic food group is very different from the other two. The fats, of which butter and lard are typical examples, consist of relatively small molecules—only about 10 times as large as those of substances like alcohol and acetic acid. Like the carbohydrates, the fats contain only carbon, hydrogen, and oxygen. When broken down, outside the body, each molecule of fat gives one molecule of glycerine and three molecules of a fat acid. The complete chemical pattern of the fats is, therefore, quite easily identified, and is much simpler than that of either the carbohydrates or the proteins.

Mineral elements are found in many different kinds of foodstuffs. It is now recognized that at least 11 mineral elements are vital to normal physical health. These are calcium, phosphorus, potassium, sulphur, sodium, chlorine, magnesium, iron, manganese, copper, and iodine. With the exception of calcium and phosphorus, which are major constituents of the bones and the teeth, these elements are present in the body in very small concentrations—as little as one part in

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2000 in the case of magnesium, and one part in 2,000,000 in the case of iodine.

The vitamins also are found in a great variety of different foodstuffs. It is impossible to discuss here the best sources of the common vitamins or their chemical natures, for they are a complex and heterogeneous lot. At least seven vitamins are recognized as definite chemical individuals, and several other substances that are suspected of exercising vitamin functions are now being investigated.

Let us now consider some of the chemical changes that constitute the digestive processes.

Chewing causes food to come in contact with saliva, which contains a substance known as ptyalin. Ptyalin is a representative of an important group of substances known as enzymes, which function in the body as catalysts—that is, they facilitate many of the chemical reactions that occur. Specifically, in the presence of ptyalin, starches are broken down into less complex substances. The proteins and fats, however, are relatively unaffected by this enzyme.

In the stomach, the food enters a region that is acid because of the presence of hydrochloric acid. Here it is brought into intimate contact with the digestive juices, which contain a second enzyme, pepsin. In an acid environment, pepsin is able to

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break down proteins into less complex bodies, just as ptyalin is able to split carbohydrates. This action requires a few hours, after which the partially digested food passes on into the small intestine.

Here a mildly alkaline condition normally prevails. As the food is received from the stomach, it encounters more enzymes in the intestinal juices. The pancreas and bile are also stimulated and begin to pump into the intestine secretions bearing still other digestive enzymes. All these secretions act together upon the partially digested food. As a result, the splitting of carbohydrates into simple sugars is completed. The sugars thus formed are identical with those formed from starches outside the body by the action of appropriate chemicals. Proteins are also broken down further in the intestine to simple amino acids—again, the same ones that are obtained from protein matter in controlled laboratory experiments. And finally, the fats are split into their simple components—fat acids and glycerin. All of these substances are readily absorbed through the intestine walls.

At the same time that the basic food materials are converted to useful products, the mineral elements and vitamins also undergo chemical alterations. The mineral elements are broken away from the organic nutrients to which they are usually attached, and are

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converted into substances that are readily assimilated. The fate of the vitamins is still somewhat uncertain. It is probable that some vitamins reach the circulatory system and the vital organs essentially unchanged, while others undergo deep-seated chemical transformations en route.

Let us assume then that all the foodstuffs, both basic and auxiliary, have been modified in the ways peculiar to the digestive processes, and that the absorbable products have passed through the walls of the alimentary canal. As far as our story is concerned, digestion is now complete. But the processes of assimilation have yet to occur. From the simple sugars, amino acids, fat acids, glycerin, and water must be constructed tissues, bone, blood, muscles, and cell walls.

Let us therefore go one step further—into some phases of the phenomenon of metabolism, the term used to designate the complex interconversions of dead food and living plasma. Let us begin with the glucose that has been formed within the alimentary canal and absorbed into the blood stream and distributed throughout various parts of the system. New organic catalysts now begin to act upon it. From some of it the body reconstructs carbohydrate—not starch, which can't be utilized at this stage, but a similar material called glycogen—which is then

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stored in the liver and in certain muscles. From these organs the glycogen can be withdrawn when it is needed, and converted once again into glucose, and finally burned to produce energy.

A similar fate awaits the fat acids and glycerin. After passing through the intestinal walls, they are recombined into fats that are essentially similar to those originally present in the food. The regenerated fats are taken up by the lymph vessels and sent into the blood. When they finally reach the tissue walls, they are burned, as in the case of the sugars, or stored in the tissues as body fat to be burned when more urgently needed.

The amino acids also pass into the blood stream and are carried thence to all parts of the body. At the various tissue walls, reactions occur which result in the rebuilding of protein matter. However, all of the amino acids formed in the system are not utilized in tissue building; some of them are oxidized or otherwise further disintegrated into simple waste materials, which can be eliminated.

Finally, the human body utilizes the mineral elements in an amazingly efficient manner, for each element is sent to that particular region where it is most needed. Calcium and phosphorus go to the teeth and bones; iron becomes part of the red blood corpuscles

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or of the chromatin substances which preside over vital cell activities; sodium, potassium, and chlorine enter the body fluids, where they perform essential and specific biochemical functions; the very minute amount of iodine essential to normal health finds its way, for the most part, into the thyroid gland. Without this very small amount of iodine, the processes of metabolism, over which the thyroid gland exercises a delicate and subtle control, would be radically upset.

It will not be possible to consider innumerable other astonishing reactions that occur in the human body, many of which are just as essential to life as those few already discussed. Among them are the modes of building vitamins from certain related nutrients present in foods; the roles played by the vitamins themselves in metabolism and bodily health; the formation in the body of various hormones, those physiologically essential factors among which are thyroxine, adrenaline, insulin, and various reproductive factors; the complex interrelations of enzymes, proteins, and hormones; the interconversions of different food types within the system; the fascinating reactions that lead to the formation of hemoglobin, the substance that makes blood red, and its equally fascinating role in the processes of oxidation.

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Thousands of scientists throughout the world—chemists, physicists, biologists, physicians—are actively engaged in studies that are extending the frontiers of knowledge of these vital phenomena, yet an almost infinite amount still remains to be done. Out of such work will some day come an answer to the eternal quest for a better physical life.

POWER FROM THE SUN

by DR. CLARENCE W. HEWLETT



DR. HEWLETT is a native of Louisburg, North Carolina. He was graduated from North Carolina A. and M. College, and received his degree of Doctor of Philosophy from the Johns Hopkins University. He has been a physicist on the staff of the Carnegie Institution of Washington, and has taught at North Carolina A. and M. College, Johns Hopkins University, North Carolina College for Women, and the State University of Iowa. Since 1922 he has been a member of the staff of the General Electric Research Laboratory.



POWER from the sun is nothing new. Practically all the power that the world now uses comes directly or indirectly from the sun's radiation.

Take coal, for instance. The energy contained in coal was stored up by the conversion of solar energy into the energy of chemical combination in the plant life of the far-off carboniferous age. Water power, too, gains its energy from the sun. We harness the fall of rivers on their way from continental watersheds to the ocean. But it is energy from the sun that evaporates the water from the ocean and deposits it at the higher levels of the watersheds.

Power from the Sun

There is another possible source of world power—one that has received much attention during the last 20 years. I refer to the ocean tides. But unlike the others mentioned, power from the tides does not come from the heat of the sun. It comes instead from the energy of rotation of the earth about its axis, and from the rotation of the earth and moon about each other and about the sun. Projects to harness the tides have been contemplated only in certain localities where the tidal water rises and falls through heights of from 20 to 50 feet. Most of these projects have never progressed much beyond the planning stage, because, in the majority of cases, the cost of the necessary power plant would be much greater than the cost of a steam power plant to produce the same amount of electric energy.

Ever since the invention of the steam engine, dreamers have speculated on the possibility of generating power by using the sun's heat to vaporize water. Time and again, experimental plants of this kind have been built. Appreciable amounts of power have been drawn from them. But all these attempts have run up against the same insuperable difficulty. The cost of the equipment for each unit of power produced cannot compete with water power or with steam plants fired with coal.

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There are other serious obstacles to solar steam engines, or in fact to any projects for the direct utilization of the solar radiation. Sunlight is intermittent. The regular alternation of day and night and the unpredictable occurrence of storms and cloudy days would interrupt the solar power plant. In order to meet this situation, various forms of power storage have been suggested to bridge over periods of darkness and clouds.

Despite the discouraging obstacles to the direct use of solar radiation, inventors and engineers are still attacking the problem from many angles. They are spurred by the thought that at some time in the future the world's coal supply will become exhausted. Hope springs eternal in the breast of the true scientist-inventor; he has faith that at any time his experiments and observations may reveal to him some new process which will free him from the usual restrictions.

The idea of directly utilizing the sun's radiant energy becomes more fascinating and attractive if we realize the immense amounts of energy that are available. Suppose we take for our unit of comparison the amount of heat that we obtain by burning a ton of coal. Then let us calculate the amount of heat that the sun radiates during one year. If we should attempt to produce that heat by burning coal, we should require

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4×10^{23} tons of coal. To express this immense amount in another way, write down the figure 4. Then write 23 zeros after it. That gives the number of tons.

But this is the total that the sun produces; the earth intercepts only a small part of it. Again assuming that we tried to reproduce, by burning coal, the heat that the sun sends to the earth during one year. This time we get 2×10^{14} tons—or 2 with 14 zeros after it.

How does this compare with the amount of coal we now burn? The population of the earth consumes for all purposes—light, heat, and power—only about half a billion tons of coal a year. Therefore the energy that comes from the sun is 400,000 times the energy we are producing with coal. So, you see, there is a tremendous amount of solar energy available. If the sun's radiant energy could be fully utilized, the amount falling on a single square yard would produce one horsepower. But the methods available at the present time entail unavoidable losses, and the best we can do now is to produce one horsepower from 4 to 10 square yards.

Dr. C. G. Abbot, of the Smithsonian Institution, has built a solar engine that has an efficiency of about 15 per cent. This compares favorably with the best modern coal-fired steam power plants, which have efficiencies ranging from 30 to 50 per cent. But despite encouraging efficiency, there is still the cost of the solar

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power plant, which would be several times greater than for a coal-fired steam plant. So it seems that we have a long way to go before steam plants operated by the sun's heat will be commercially utilized.

From time to time it has been proposed that we use the thermoelectric effect to harness the sun's energy. When two wires of different metals are joined together at their ends, thus making a closed circuit, and one junction is heated while the other remains cold, an electric current is set up in the circuit. This current flows for as long as the two junctions are maintained at different temperatures. Many experimental generators have been built on elaborations of this principle. But the best efficiencies have been 1 or 2 per cent, and the cost of equipment per unit of power is so great that at present it is entirely out of the question to commercialize this method of power generation.

During recent years a new type of photoelectric cell has been developed. It is called a "blocking-layer" cell, and it has led to some speculation as to its possibilities for converting sunlight directly into electrical energy. One form of blocking-layer cell consists of a thin layer of the element selenium mounted on an iron plate. On the free surface of the selenium there is laid down a semi-transparent layer of an electrical conductor, such as platinum or gold. When light falls

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on the layer of selenium, electrons are liberated, and these electrons are conducted away by the semi-transparent layer of metal. If the iron plate is connected to one terminal of a current-measuring instrument, and the platinum or gold layer is connected to the other terminal, an electric current of from 15 to 20 milliamperes per square inch of cell surface is produced when the cell is exposed to sunlight. The power output is about one $\frac{1}{1000}$ watt per square inch of cell surface. In fact, it has been found possible to construct a small and delicate electric motor that runs very nicely when connected to a cell so illuminated. But an output of 1 milliwatt per square inch means only $1\frac{1}{3}$ watts per square yard of sunshine, whereas the actual power in that much sunshine is roughly 746 watts. The efficiency is a little less than one-fifth of 1 per cent. And here again the cost of equipment is so tremendous that power generation on a commercial scale is entirely out of the question. To generate one horsepower with these blocking-layer photocells, 570 square yards of photoelectric surface would be required.

One of the reasons for the low efficiency is that only a very small part of the radiation from the sun is effective in generating electric energy. Roughly speaking, only the visible light from the sunlight is

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transformed into electric energy, while the longer wave lengths—the heat radiation—serve only to raise the temperature of the photoelectric cell. But even if we consider only the sun's visible radiation, still the efficiency is but 2 per cent.

While the efficient generation of power from sunlight with these new photoelectric cells may not be impossible, yet considerable improvements must be made before it is practical. We must first find ways of increasing the efficiency of transformation of solar radiation into electric energy, and we must also find ways of utilizing the heat radiation which now serves no useful purpose in the photoelectric transformation.

And what is said about the method of photoelectric cells applies almost equally well to the other methods for utilizing the sun's radiation. The power is there—power greater than we can ever hope to utilize. It remains for science to find ways of economically transforming that power into forms that we can use. And it explains why, in laboratories all over the world, engineers and physicists are at least thinking about new ways of putting to work the tremendous flood of energy that comes from the sun. This energy is free; it makes possible life on our planet; but we are powerless to control or alter the rate of its arrival.

ODORS AND THEIR DETECTION

by DR. NEWELL T. GORDON



DR. GORDON, born in Boonton, New Jersey, attended Princeton University, and there received his Doctor of Philosophy degree in the field of chemistry. After one year with the Bureau of Explosives, Department of Labor of the State of New Jersey, he joined the Chemical Warfare Service of the A.E.F. Joining the General Electric Company in 1919, he went to the General Electric Research Laboratory, in Schenectady, in 1926.



WHENEVER a search for some lost article seems all but hopeless, we say, "It's like looking for a needle in a haystack." Yet, that is just about the problem that your nose solves with astonishingly little effort; in fact, your nose not only finds the needle but also distinguishes it from a pin in that same haystack. For the normal human nose can detect and identify one part of odor in more than a billion parts of air—equivalent to finding a needle of medium size in a haystack 25 feet square and 25 feet high.

Of course, the threshold values, or lowest concentrations we are able to detect by the sense of smell, vary widely for the different odors, and sometimes strong odors have relatively high threshold values. For exam-

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ple, camphor, ether, and oil of peppermint all have high threshold values, while vanillin and musk have the lowest threshold values recorded. Vanillin and musk may be detected in concentrations 1000 times less than that for oil of peppermint. A dog, whose ability to follow a scent is so well known, can, undoubtedly, detect odors in much lower concentrations than have been measured experimentally, and the fact that this ability is influenced by the direction of the wind is one indication of the nature of odors.

It is generally accepted that odors are molecules of volatile substances that pass into the air in the same manner as water evaporates. If odors, like light, were due to radiation, they should spread equally in all directions and should not be affected by wind or convection currents in the air. However, we all know that drafts are of prime importance in the spreading of odors, and therefore odors cannot be due to radiation.

An interesting experiment carried out in the Research Laboratory some time ago demonstrated that odors are caused by molecules and not by solid particles. In the first part of this experiment, air containing tobacco smoke was passed through an electrical precipitator; in the second part, through a filter of activated charcoal; and in the third part, through an

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apparatus containing both the electrical precipitator and the charcoal filter.

Perhaps I should explain that the electrical precipitator is a device, originally invented by Cottrell, which in the simplest form consists of a metal tube with a wire stretched along the axis. When a high voltage is applied between the wire and the wall of the tube, any solid particles contained in the gas or vapor passing through the tube are eliminated by precipitation on the walls. Activated charcoal, used in the second apparatus, is a specially selected charcoal so treated with steam at high temperature as to make it especially efficient or active, as the name implies, in the absorption of gases. In other words, this treatment makes charcoal a good sponge for gases.

Continuing now with the first part of our experiment, the solid particles of tobacco smoke were eliminated by the electrical precipitator, but the odor passed through practically undiminished. In the second part of the experiment, the smoke-laden air was passed through a filter packed with activated charcoal. This time the odor was greatly diminished, but the smoke came through in clouds. Activated charcoal absorbs organic odors, but solid particles of smoke bounce along from one particle of charcoal to another,

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rendering the filter ineffective for the elimination of smoke.

Finally, both the particles of tobacco smoke and the odor were eliminated when the smoke-laden air was passed through the electrical precipitator and the charcoal filter in series.

Since the evidence is conclusive that odors are molecules of readily vaporized substances, we may next ask by what process our sense of smell functions. The olfactory mucous membrane, or organ for detecting odors, is located in the upper part of the nasal cavity and has a yellowish color which contrasts with the rest of the chamber. Its area is approximately 1 square inch on each side of the nose. From this membrane nerve fibers gather together, forming the olfactory nerve, which leads directly to the brain. Each nerve fiber comes from a sense cell that forms a part of the olfactory organ, and all such cells reach through this organ to the exposed surface. Here each cell terminates in six to eight relatively long filaments, or hairs, which float in the thin layer of mucous that covers the olfactory surface. Molecules of an odor strike this surface, dissolve in the fluid, and undergo chemical reaction. For this reason the sense of smell and the sense of taste, as well, are known as chemical senses.

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In ordinary respiration the passage of air through the nose excites the sense of smell to only a limited extent. This is accounted for by the fact that the air follows a curved path and does not reach a point as high as the olfactory area except by diffusion. If we sniff, however, a turbulence is caused in the air flow, and greatly increased numbers of molecules are brought into direct contact with the sensitive area, producing a wide variety of sensations depending upon the chemical reactions involved.

The quality of an odor is usually named by association with the object from which it emanates—as the odor of moth balls, of rubber, of paint, kerosene, shoe polish, roses, violets. Attempts have been made to classify odors, and Henning, one of the world's great authorities on this subject has arranged them in six groups:

1. Spicy odors, such as cloves and sassafras oil.
2. Flowery odors, such as heliotrope and geranium.
3. Fruity odors, such as orange and banana.
4. Resinous odors, such as turpentine and Canada balsam.
5. Burnt odors, such as tar and pyridine.
6. Foul odors, such as carbon bisulphide and hydrogen sulphide.

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But many odors cannot be accommodated even by this classification, and it becomes necessary to describe some odors as belonging to two groups. A classification on the basis of chemical structure also encounters many difficulties and inconsistencies, so that no single system is satisfactory for all purposes.

By comparison with this situation for odors, the classification of tastes is simple and quite definite. There are really only four well-defined kinds of taste—sour, salty, sweet, and bitter—each one associated with a particular area of the tongue. The wide variety of so-called tastes is really due to our sense of smell, and we all know how a cold in the head detracts from our enjoyment of even the most savory foods. Some people even claim that apples and onions taste almost alike if eaten while the nose is held tightly closed.

Recent years have made us all familiar with the photoelectric tube, which acts as an electric eye, and with the microphone, which acts like an electric ear. Is there, or can there be devised, an “electric nose”?

It is evident that any electrical device to detect and measure odors must be not only exceedingly sensitive but also very selective. Gases and vapors have one property which can, perhaps, be made to serve this purpose. They are able to absorb radiation of characteristic bands or wave lengths—particularly in the

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infrared region beyond the red or long-wave-length limit of the visible spectrum. This property of gases to absorb heat rays was demonstrated as long ago as 1865 by the famous physicist John Tyndall, who succeeded Faraday at the Royal Institution. He found that the amount of heat rays absorbed by different gases and perfumes varied widely. If we were to draw an analogy with his experiment, we might represent his source of heat as the sun, the perfumes as clouds of different densities, and his measuring instrument as a thermometer. The thermometer reaches the highest temperature in the direct rays of the sun, decreases slightly when a light cloud obscures the sun, and falls markedly when a dark cloud passes over. Tyndall used a radiant heater as his sun or source of heat waves, a tube containing perfume-laden air as the clouds, and a sensitive electrical device, a thermo-electric pile, as his thermometer.

He found that if he used the amount of heat absorbed by air as a standard, calling it unity, the perfume of sandalwood absorbed 32 units, oil of cloves 34 units, and aniseed 372 units. Here is an example of an electric nose that can be made quite sensitive. It can find the needle in the haystack, but it cannot distinguish it from the pin. It cannot distinguish between sandalwood and cloves, or between a high concentra-

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tion of sandalwood and a low concentration of aniseed. If, however, an odor has the property of absorbing rays of a particular or characteristic wave length, the method might be used as a means of identification.

A somewhat similar method has been developed for the detection of mercury vapor, and it has been in successful operation for several years. In this device a characteristic wave length in the invisible ultraviolet region is absorbed by mercury, and the amount of absorption is a measure of the concentration of mercury present. A photoelectric tube is used in place of the thermopile; and by simply reading the variations in current through the photoelectric tube, it is possible to measure the amount of mercury in the air. Five atoms of mercury in a billion molecules of oxygen and nitrogen of the air can thus be detected.

Of course, mercury has no odor, but it is well to have a good electrical nose for mercury because, in high concentrations, mercury vapor causes certain toxic symptoms. A concentration of one part in 10 million by volume is considered safe, and since this device is able to sound an alarm when the concentration of mercury is only one-twentieth of this amount, it affords ample protection for situations in which the nose fails to warn us. This means, using the analogy of the haystack again, that the mercury detector could

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find a needle and also distinguish it from a pin in a haystack 10 feet square and 10 feet high—a stack not quite so large as the 25 foot example illustrating the sensitivity of the nose, but still large enough to emphasize the extreme sensitivity of the mercury detector.

The complexity of the factors involved in the sense of smell has thus far retarded the development of an electrical device for detecting odors, but the success of the mercury detector encourages further work. Also, recent improvements in instruments for the detection of infrared rays illustrate the advances that may eventually lead to the successful development of the electric nose.

LILLIPUTIAN CHEMISTRY

by DR. HERMAN A. LIEBHAFSKY

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DR. LIEBHAFSKY was born in Zwittau, Austria-Hungary. After studying at the A. and M. College of Texas and the University of Nebraska, he received his degree of Doctor of Philosophy from the University of California, where he was an instructor in chemistry for five years. Since 1934 he has been a physical chemist in the General Electric Research Laboratory.

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THE range of the quantities used in chemistry is very wide. The foreman of a mine smelter deals with tons of material; the laboratory chemist usually works with a millionth of a ton, or a gram; the microchemist works with a millionth of a gram, or a *gamma*. This term, the Greek equivalent for the letter *g*, has been coined to describe this minute unit of mass, which characterizes the scale of operations of microchemistry.

When I was much younger, I remember how impressed I was with the delicacy of an ordinary chemical balance. "This balance is so delicate," I was told, "that it will weigh your signature." A piece of paper was weighed; I wrote my full name (which fortunately is fairly long) upon it, and the paper was

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weighed again. Sure enough, the difference was detected by the balance.

Recently I performed a similar experiment on the microbalance in our laboratory—but this time I used, instead of my full name, only a period made with a sharp-pointed pencil. Yet that period weighed 10 gammas, or enough to be very noticeable on the balance. Each time you dot an *i*, your pencil becomes several gammas lighter. Each time a raindrop falls, from 50,000 to 100,000 gammas strike. One cent will buy nearly 10,000 gammas of gold.

From another point of view, however, the gamma is immense. A gamma of gasoline, for example, contains enough molecules so that they might, if they could be laid end to end, reach well across the Atlantic Ocean. This point is important, for atoms or molecules in such large crowds are good, law-abiding citizens; they behave, on the average, in a reproducible manner. Catch them alone, however, and their behavior is not always predictable. Because the gamma contains so many molecules, the microchemist knows that the laws that are valid for grams or pounds of matter hold also in the realms of microchemistry. He is sure that the relationships governing the reactions of a speck of material almost invisible to the naked eye are the same relationships that govern its reactions in bulk.

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But why work with such small amounts? Well, sometimes larger amounts are not available, as when it is necessary to examine the debris that surrounds a pinhole leak in some sealed vessel. Or the substance may be so precious that the amount consumed in analysis must be kept at the minimum. Cases like this are numerous; the less important involve substances like gold, which everyone knows is precious, while the more important involve substances like vitamins and hormones, whose initial preparation or isolation often requires almost unbelievable amounts of time and labor.

Again, it may be necessary to establish the composition of an heirloom or antique—smashing this in a mortar to obtain a large sample is scarcely advisable, and it is entirely unnecessary if microchemical methods are employed. Valuable paintings by old masters have been identified by removing and analyzing amounts of pigment so small as to escape any but the most minute scrutiny.

There are still other reasons for working with small quantities. Many substances, like explosives and poisons, which are dangerous or obnoxious to handle in gram amounts, can be studied conveniently in amounts much smaller. Time, too, can often be saved by microchemical methods with no loss of accuracy—a few

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drops of solution can be evaporated much more rapidly than a cupful, and a precipitate the size of a pinhead dries more rapidly than one a hundred times as large. And finally, since small platinum crucibles and similar expensive pieces of equipment cost less than large ones, the same amount of money will buy more microchemical apparatus.

Naturally, the microchemist cannot carry out his work according to traditional laboratory methods. For the conventional beakers and test tubes must be substituted vessels in the form of tiny capillary tubes. Solutions cannot be poured out of these any more than water can be poured out of a sponge, and for much the same reason. So the microchemist transfers his solutions by small loops at the end of a wire, or by employing tubes small enough to fill themselves when they are inserted beneath the surface of a liquid. The behavior of liquids in small glass vessels is governed by surface-tension forces—the same forces that help water to enter the roots of a plant.

Heating is often carried out on the steam bath, because heating with any sort of a flame is liable to blow the sample right out of the tube. When flames must be used, they are so small that a lighted match is a roaring inferno by comparison. Separation of solid from liquid is usually accomplished, not by filtering,

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but by centrifuging or “spinning down,” using the principle by which clothes are dried in the “spinner” type of washing machine.

In many of his tests, a chemist observes how a precipitate forms in a test tube; the microchemist obtains the same information by observing his much smaller sample under a microscope. The microscopic evidence is the more convincing because it magnifies each crystal so that its characteristic form can be observed. For the observer with a microscope, each substance writes its own signature.

Microchemical analysis often develops into a kind of detective work. Where the ordinary chemist has evidence, the microchemist has only clues. Smudges, smears, almost microscopic spots of corrosion—these, many times, are important bits of evidence in tracking down and eliminating troubles in the design of machinery.

Everyone is familiar with the vacuum tubes that operate our radios. In many of these tubes there are reactions occurring during operation which even yet are not well understood. Sometimes the glass walls become discolored—but so slightly as to remain transparent. By microchemical methods it is possible to show that the discoloration is due to mixtures of several metals that evaporate from the filament. And it is possible, even with films so thin as scarcely to

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be visible, to determine quite accurately the amounts of each metal. Evidence of this kind helps us to understand the reactions occurring on the filament, and guides us in the building of better tubes.

The presence or absence of alcohol in blood and living tissues is an important question, quite apart from its bearing on the consumption of alcoholic beverages. By a series of microchemical procedures, almost unrivaled for elegant conception and execution, three New York City chemists were able to prove that ethyl alcohol in minute amounts is present in the brain, liver, and blood of abstinent human beings and of certain animals. The amount of alcohol in pigs' brains is such that about 100 pounds of brains are required to yield one drop of alcohol. Yet the presence of this small amount of alcohol is an important clue in establishing what chemical reactions keep animal life going.

Microchemistry is a comparatively new field. Much of the early work was done by men working in the so-called life sciences—biology and medicine. But today few sciences have available such a variety of methods as does microchemistry, and the success of chemistry on a Lilliputian scale will, in time, undoubtedly modify all laboratory procedures that can be done more economically or more conveniently with amounts of material smaller than those now customary.

HOW EARTHQUAKES GIVE US THE INSIDE FACTS

by EDWARD S. C. SMITH



THE SURFACE of the earth is well known, but how much do we know of the structure and the materials of the earth itself? The deeper mines, such as the gold mines of South Africa, are about 8000 feet in vertical depth, and in California oil is being obtained from drillings reaching to 10,000 feet. Therefore, in round numbers, 2 miles is about the present limit to which man has penetrated into our planet. The earth's radius is approximately 4000 miles; therefore, actual experience goes but five-hundredths of 1 per cent of the distance from surface to center. The observed increase of pressure and temperature with depth is such that little hope is held out that man will ever be able physically to penetrate to levels thousands of feet beyond those now attained.

There are many questions we would like to have answered concerning the earth's real interior. If the ordinary rocks at the earth's surface are of a density of about two and a half to three times that of water, why is it that the earth as a whole is about 5.6 times as heavy as water? Is the center of the earth metallic?

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Is it solid? Is it liquid? Is it gaseous? For answers to these and like questions we turn for assistance to seismology, that branch of earth science which deals with earthquakes and their related phenomena.

An earthquake is the trembling or, more strictly speaking, the vibrating of the earth as a result of energy suddenly released by adjustments that are taking place within the earth itself. The earth's crust is continuously being subjected to strains of various kinds the causes of which are not fully understood. As these strains accumulate, they finally become greater than even the strongest rocks can withstand. Fracturing on a grand scale then occurs. These earth fractures are called, by geologists, faults. The vibrations, resulting from the realignment of the broken crustal blocks, pass through and around the earth; they may be intense enough to damage or destroy buildings and other structures, or they may be so slight as to be detected only by delicate instruments called seismographs—devices for recording earthquake vibrations at great distances from their origin. Many such instruments are in operation in all parts of the world, and from them valuable data are constantly being obtained.

Earthquakes caused by adjustments along faults are called tectonic quakes (from the Greek, *tektonikos*,

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meaning that which is concerned with building), because faulting is closely associated with mountain building and similar crustal movements. A few quakes are associated with volcanic disturbances, but these are usually local in character. Still fewer are the so-called deep-focus earthquakes, which seem to be connected with adjustments at depths of 200 miles below the surface. Most tectonic quakes appear to originate relatively near the surface, at depths of 25 miles or less, and are referred to as shallow-focus earthquakes.

The crustal displacements along faults may frequently be seen at the surface after earthquakes have taken place. After the great San Francisco quake of April 18, 1906, horizontal shifts of the ground, up to a maximum of 21 feet, were to be observed along the San Andreas fault. In 1891, a disastrous quake in Japan produced horizontal displacements up to 12 feet, combined with vertical displacements up to 20 feet, along the fault responsible for that earthquake. The faults themselves may often be traced for many miles on the earth's surface; thus we are able to obtain visible evidence of large-scale faulting associated with many of the great earthquakes of recent times.

The origin of the earth vibrations resulting from faulting may be illustrated by a simple experiment. If a small piece of wood about the size of a common desk

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ruler be bent in the hands until it breaks, the ends will vibrate very rapidly at the moment of fracture, sometimes with sufficient energy to cause a sharp, stinging sensation in the palms. The elastic rebound of the wood after fracture causes the vibration. The belief that the earth's crust acts in a similar way when fractured has led to the general acceptance of what is called the elastic-rebound theory to explain the origin of earthquake vibrations.

Studies of earthquakes, which may be said to have been begun in 1846 by that pioneer in seismology, Robert Mallet, show that when faulting takes place vibrations of three different sorts are set up. The first vibrations are analogous to sound waves; that is, they are longitudinal or compressional waves which vibrate back and forth in the direction of their propagation and which alternately put earth particles under compression and then under tension. As these are the first waves to appear, they are called the *primary* or, for short, the *P* waves. Their average velocity is 3.4 miles per second.

Following immediately upon the heels of the compressional primary waves comes a second group of vibrations which are transverse or distortional waves that cause the earth particles to swing back and forth at right angles to the direction of propagation. These

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transverse waves have the somewhat lower velocity of about 1.8 miles per second and are called the *secondary* or, for short, the *S* waves. Both the compressional and the distortional waves spread out in all directions from their source with approximately spherical wave fronts.

The third and last set of waves to be generated are those which travel along the surface of the earth. They are of greater length and amplitude than the *P* or the *S* waves, and they are of longer duration than either of the others. These waves have been called the *main* waves or *long* waves and are technically referred to as the *L* waves. They appear to have been seen sweeping over the surface by numerous observers, in spite of their speed of 2.3 miles per second. These *L* waves become very important when considering surface effects of earthquakes, but as we are now concerned with what is happening underground, we shall confine our attention to the *P* and *S* phases. Three things ought to be remembered about them. First, their velocities are dependent upon the elasticity of the matter through which they pass; second, their velocities depend also upon the density of that matter, the denser it is the slower the wave will travel; and finally—a very important point—the *S* or transverse waves will not pass through a substance having the properties of a liquid.

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Let us now digress for a moment to consider the seismograph, the instrument which records these several types of earth vibrations. In principle the ordinary seismograph is a delicately balanced horizontal pendulum, in some types an inverted pendulum, which carries a very heavy bob, called the *steady mass*. The pendulum is attached to a strong upright support, which, in turn, is fastened to a massive pier. A light boom coupled to the pendulum serves to record the earth movements, considerably magnified, either mechanically or photographically. When in operation, the steady mass tends to remain quiet, acting as the fulcrum of a lever, while the rest of the machine partakes of the earth motion, recording it as a complex sinuous curve, the seismogram, which it is the task of the seismologist to analyze.

Various damping devices are necessary to prevent the pendulum from swinging in its own natural period and thus superimposing its own vibrations upon those of the earth. A complete seismograph should consist of two pendulums set at right angles to each other in order to record all possible horizontal vibrations, and if possible, a third instrument to respond to vertical wave motion. A necessary adjunct to the seismograph is, of course, a timing device for obtaining the accurate

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times of reception, at the station, of the various phases of any earthquakes being recorded.

It was early discovered that, knowing the time of arrival of the several phases of earthquake vibrations and their velocities, time-distance curves could be constructed from which the distance of seismograph stations from the origin of the earthquake could be deduced. With the modern time-distance tables, data from three stations only are needed to permit the very exact location of an earthquake. And it is in the studies of wave velocities originally begun for the purpose of finding where earthquakes occur that much light has been shed on the nature of the earth's interior.

It has been found that the velocity of the *P* waves increases with depth until they reach a point about 1800 miles below the surface—very nearly half way to the center of the earth—where their speed, which has increased now to about 8 miles a second, suddenly drops off to about 5 miles a second, indicating an abrupt and doubtless a very fundamental change either in the material of which the inner earth is composed or in its physical condition. The *S* waves behave essentially like the *P* waves, gradually increasing their velocity with depth until this 1800-mile region is encountered, where they apparently disappear. When we remember that the *S* waves are of the transverse

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sort, which cannot pass through a liquid, this appears as a rather startling fact.

The earth's core, somewhat over 4000 miles in diameter and including about one-sixth of its volume, must then be of the physical nature of a liquid or gas, yet one of high density, say around nine or ten times as heavy as water, or just a little greater than the density of metallic iron. Here is a clue to the density of the earth as a whole, to which I have referred.

It should be noticed that both P and S waves increase their velocity with increasing density until the core is reached, which can only mean that the elasticity of the outer shell increases enough to neutralize any density increase. Doubtless the temperature increase, and perhaps the physical condition as well, in the outer shell accounts for this situation.

The transition from the outer shell to the inner core is abrupt, indicating a sudden change in the nature of the materials there or their physical condition, and the bounding surface between the shell and core is called a discontinuity. Earthquake waves reaching such a surface of discontinuity may be variously reflected or refracted, or may even follow the surface of discontinuity itself, and our seismograms show that this is exactly what happens.

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In addition to this major discontinuity when the core of the earth is reached, other lesser discontinuities have been found to exist at depths of $7\frac{1}{2}$, 23, 37, and 750 miles, as indicated by the behavior of the *P* and *S* phases of earthquake waves.

We may sum up as follows the deductions that have been made from seismic studies concerning the interior of the earth. The earth is made up of concentric shells of different thicknesses whose densities increase with depth, the central core being perhaps made up of metallic iron with some nickel. This metallic core has a radius of about 2100 miles and an average density of about 9. Next come several transitional shells with a total thickness of about 1100 miles and average density of about $5\frac{1}{2}$ to 6, made up perhaps of a mixture of metallic iron and silicates. Then comes a shell about 700 miles thick, of average density of 3.4, made up of matter of the general nature of heavy silicates of iron and magnesium. Finally, a 50-mile-thick shell of light silicate matter, on the outside of which man has found his home.

Is this the whole of the story? By no means; there is still much to be done with the information which every earthquake traces for itself by means of the seismograph. Earthquakes give us the inside facts, and it is the job of the scientist to interpret them correctly.

OZONE

by DR. FRANCIS J. NORTON



DR. NORTON was born in Fort Plain, New York, and did his undergraduate and graduate work at Yale University. He was for six years a research chemist for the Solvay Process Company, at Syracuse. Since 1930 he has been a member of the General Electric Research Laboratory.



THE air we breathe is made up, mainly, of two gases—nitrogen and oxygen. The chemical shorthand symbol for oxygen is the letter O, and it stands for a single atom. But ordinary oxygen, as it occurs in the air or in tanks of compressed oxygen, consists of two oxygen atoms closely linked together. We write this as O₂. Two atoms of oxygen thus joined are called an oxygen molecule, and may be thought of as having a dumbbell shape.

But single atoms of oxygen do exist in a few places. One such place is 100 miles up in the atmosphere, where they give color to the Northern Lights and add to the very faint greenish hue of the night sky. Another place where single oxygen atoms are found is in electric discharge tubes in the laboratory.

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When dry air or oxygen is passed through a high-voltage electric discharge, a smooth blue- or purple-colored glow is seen, and some of the oxygen molecules are torn apart by the intense electrical forces in the discharge. This produces single atoms of oxygen, but these single atoms do not like to exist alone, and in a small fraction of a second they combine again. Some of them go back to ordinary molecules of O_2 , but a certain fraction link up to make a new kind of molecule with *three* atoms of oxygen— O_3 . This new molecule is ozone.

The new form of oxygen is a colorless gas. It has a distinct and very powerful odor—the characteristic odor we notice when electric sparks or lightning discharges have passed. In ancient times, the poet Homer mentioned the characteristic odor that accompanied the thunderbolts of Zeus. As Lawrence of Arabia has translated it:

“Then Zeus thundered and at the same instant struck the ship with his lightning. She reeled from stem to stern at the divine stroke, and was filled with brimstone fumes.”

The fumes Homer described were not from brimstone—that is, from burning sulphur—they were ozone and the oxides of nitrogen. But when occurring in very dilute form, so that they can just be smelled, the odors

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of ozone, sulphur dioxide, nitrogen oxides, ammonia, and chlorine are so nearly the same that they are difficult to distinguish. Homer can, therefore, be forgiven for confusing ozone and sulphur dioxide.

A small amount of ozone may have a refreshing odor, and the pure air of mountain tops sometimes has in it a little ozone that can be smelled. However, breathing ozone is not a pastime to be recommended. Not long ago, experiments were reported on the effect of ozone on guinea pigs. Over a period of weeks, the animals breathing such low concentrations as one part of ozone in a million parts of air had shorter lives than animals breathing normal air, which ordinarily contains a thousandth of this amount, or one part in a billion. The ozone irritated the lungs and bronchial tubes of the experimental animals, and pneumonia was frequent. These experiments indicated that it might be highly dangerous to inhale, for an hour, air containing 50 parts of ozone per million, and many chemists can testify that a single breath of air containing 1 per cent of ozone produces extremely uncomfortable results.

Various gases differ in their activity, or readiness to combine chemically with other molecules. Helium and argon, for instance, are almost totally inactive, and are called "inert" gases. Nitrogen is rather inert and

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will combine only under certain special conditions, such as high temperatures and pressures in nitrogen-fixation factories, or in the soil with the aid of nitrifying bacteria. Ordinary oxygen is much more active. It combines with the blood in every breath we take, and it warms our homes by uniting vigorously with coal or oil to give flame.

In bleaching leather and linens, we may use the oxygen of the air, working with the sunlight and the dew, to remove the yellow color. Ordinary oxygen does this by uniting with or oxidizing the yellow constituent of the material, but the process may take days or weeks. Ozone can bleach in a few seconds or minutes.

Ozone oxidizes and kills the bacteria in water, just as chlorine does. It is widely used in France for this purpose. It is also of use in controlling mold growth on meats in cold-storage warehouses, and it can be used to accelerate the drying of linseed-oil types of paint.

Thus ozone has its uses, and that is one reason why, in laboratories all over the world, scientists have spent much time studying it. Most of its uses derive from its most characteristic property, its instability. In the course of a few hours or days, depending on conditions, it breaks down to form ordinary molecular oxygen— O_2 .

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Some very interesting experiments are possible with ozone. Take a rubber band. Hang a weight on it to stretch it to three times its length. Suspend it in a box with glass sides, where it can be watched. In the normal course of events, it would stay like this for weeks or months. But run a stream of ozone through the box; while you watch, in just a few seconds, the rubber shreds, cracks, breaks, and down comes the weight with a bang. Ozone is very destructive to rubber.

This reaction of ozone with rubber raises a most interesting point. Ozone exists in the upper atmosphere, at levels 20 to 40 miles above the earth, in considerable quantity. As attempts are made to reach higher and yet higher levels with sounding balloons and stratosphere balloons, this ozone must be taken into consideration. It is likely that the contact of stretched rubber balloons with ozone would prove disastrous in a short time.

In the visible region of the spectrum, ozone is practically colorless and readily allows light to penetrate it. But in certain portions of the ultraviolet spectrum, ozone possesses an intense band of "invisible color," an absorption band. Weight for weight, in this region ozone is as opaque to ultraviolet light as a sheet of metal is to visible light.

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This absorption of ultraviolet by ozone can be strikingly demonstrated in the laboratory. A mercury arc lamp produces large quantities of ultraviolet radiation. If the envelope of the lamp is of quartz, the ultraviolet can pass out through it. And if the lamp is surrounded by a jacket that transmits ultraviolet, but is opaque to visible light, then the lamp becomes an intense source of invisible radiation—not apparent to the eye, but able to produce some interesting effects.

Among them, it is able to excite fluorescence in many materials—that is, to cause these materials to glow with bright, visible colors. Therefore, if a screen coated with a fluorescent paint is placed in the range of the invisible radiation of the ultraviolet lamp, it will glow with a brilliant light all its own. Suppose, now, one holds his hand between the lamp and the screen. The shadow of the fingers is thrown on the screen, as would be expected; the hand, obviously opaque, is cutting off the radiation from the lamp.

But connect an ozone generator to a glass tube, and place the open end of the tube halfway between the lamp and the screen. The ozone is colorless and invisible—at least, it is by daylight. But with ultraviolet there is a different story. The ozone escaping from the tube will throw a shadow on the screen, a shadow which curls and billows like black smoke. The ozone,

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escaping from the glass tube, is as opaque to ultraviolet as was the intercepting hand. No one who has seen this experiment can doubt the absorbing power of ozone for ultraviolet.

The amount of ozone in the atmosphere above us is measured by studying the absorption of ultraviolet light from the sun. These measurements are made photographically or with a quartz photoelectric tube, for both these devices can see the regions in the spectrum invisible to our eyes. In this way ozone in high levels of the atmosphere, through which sunlight or moonlight has passed, can be determined.

If all the air in the atmosphere were compressed to uniform sea-level pressure, there would be a layer 5 miles deep, of which 1 mile would be oxygen. Compressed to the same extent, all the ozone in the atmosphere would form a layer only $\frac{1}{8}$ inch deep. Yet this $\frac{1}{8}$ -inch layer of unstable gas is what acts as a valve, so to speak, for the ultraviolet radiation from the sun to the earth. If there were no ozone in the atmosphere, it is probable that the intense ultraviolet light from the sun would be fatal to nearly all forms of life as we know them. With more ozone, so much ultraviolet would be cut out that the natural development of vitamin D, so essential to animal well-being, would be seriously curtailed.

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This, then, is the picture of ozone—unstable tri-atomic oxygen, O_3 ; formed electrically and having a characteristic odor; very active, and a harmful or a useful agent, according to the application we make of it; forming and disappearing in the atmosphere high above us, where it is a barrier to the intense ultra-violet light of the sun, making life possible on the earth.

THE EARTH AS A DIARY

by KARL A. PAULY

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MR. PAULY is a native of Somerville, Massachusetts. He was graduated from the Massachusetts Institute of Technology, was employed with the New England Telephone Company, and joined the General Electric Company in 1899. Until his retirement, in 1937, he was Engineer of the Company's Industrial Department, and was the designer of many important installations of electric apparatus. The study of geology and paleontology has occupied his leisure time for many years.

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WHERE did the earth come from? How long has it been here? What is its past history, and where is it going from here? We may ask these questions, and not realize that answers to some of them are to be found in a diary in which our good earth has recorded many important events of its past. And at this very moment, the rivers and lakes are engaged in writing a story of today for the benefit of those who will be here to read it millions of years hence.

Even the dreaded earthquakes are but vibrations caused by Nature's pen as it records an important event in earth history. The rocks, which we frequently admire, are but the pages of this diary that our earth

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has kept so faithfully through millions of years that we may satisfy our curiosity by prying into its past.

What do we find as we read the dusty and oft-times badly worn pages of this diary? Well, we learn that the earth is probably billions of years old; that it has had a very interesting career; that it was once molten and that for a long time after the crust had covered the molten interior there were tremendous volcanic disturbances; that the crust has been and still is being bent and folded by the enormous strain caused by contraction as it cools down. We learn that nearly all, if not all, parts of our present dry land have been under the ocean at least once, and most of them many times. So complete is the record that we can often trace the progress of these oceans as they have worked their way inland, and we can discriminate between the shallow seas and the deeper oceans, the sandy beaches, the mud flats, and the coral reefs. Sometimes the ripples in the sand on the ancient beaches and the rain-drops on the ages-old mud flats are clearly visible.

We also learn that great mountain ranges have existed where none are found today—these earlier mountains having been worn away by the destructive action of the weather and carried by the winds, the brooks, and the rivers to the valleys, the lakes, and the oceans below. So vast were some of these mountains

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that sedimentary rocks miles in depth and thousands of square miles in area have been formed from the sands of which their rocks were once composed.

We find scattered here and there throughout our diary interesting stories of glacial periods that have occurred many times in the past, during which vast areas that now enjoy temperate climate were covered with ice thousands of feet thick during perhaps hundreds of thousands or even millions of years. We learn that our earth has been inhabited for millions of years by highly organized life, the very beginnings of which are still unknown, because the early pages of earth's diary either have been destroyed or still remain hidden away in some undiscovered place under great depths of overlying rock. Although there is no definite proof of it, the evidence indicates that the development of life on a large scale began in the sea, for there is no record of land life found in the rocks until after very great progress had been made in marine life. Although definite knowledge of the earliest life is still lacking, some clue to its character in some cases can perhaps be gained from a careful study of the very beginnings of the life cycle of some of our present-day animals. But until discovered, these early pages of our earth's history will remain a powerful stimulant, urg-

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ing us on in our search for the beginnings of life on our planet.

We find in studying our record that the early life has been affected by its environment—that the animals of the mud flats and quiet shallow seas differ from those of the sand beaches and deeper and more open waters. We find recorded the complete life histories of many animals that have come into existence in one locality, spread to a greater or less extent throughout the waters of the earth, and then passed completely out of existence never to appear again, leaving only their skeletons behind to assist our imaginations in picturing them in actual life. On the other hand, the very beginnings of others, which have carried on through hundreds of millions of years and are now commonplace in our waters today, are recorded in this rock diary.

But in all of this we note progress. We find that the development of life has been orderly. In it we find our clues to biological evolution and our basis for the law of the survival of the fittest. The gradual growth in size of most animals with the progress of time is very striking. Full-grown starfish, when they first made their appearance in the early Ordovician period, were about the size of a 25-cent piece, and I have a perfect

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young specimen, which I found attached to a piece of coral, that is no larger than a pinhead. Shellfish resembling our modern clams and scallops were at that time, for the most part, no larger than small peas or lima beans.

Now that I have stated in a very general way what our diary contains, you are perhaps wondering how we—that is, you and I who are not geologists or paleontologists or some other “-gists”—can enjoy the thrill that comes from reading firsthand from this diary. First we must learn the language in which this diary is written. Immense pleasure may be derived from nature, but studying nature is like putting money in the bank. It pays excellent returns on what we put into it, but we must make the deposit before we can collect the interest. I fear the trouble with most of us is a desire to collect our interest before we earn our principal. If we want to cash in on nature, we must be willing to devote a little time to the study of some of the fundamentals involved. And if we do, with that knowledge as a deposit in the bank, we will derive an immense amount of pleasure in return for our efforts. Learning enough to begin reading the simpler stories of our earth's history is not a difficult task, and I assure you that the interest of these first stories will provide the urge to continue the study further.

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The first step is to learn the characteristic rocks of our district and the major subdivisions of our earth's history to which they belong. This, as I have said, is not a laborious job if we do not go too much into detail. Then we should become interested in the record of animal life to be found in these rocks. This is a very natural sequence, because it is through the animal life that they contain that many of the rocks are known. Inexpensive elementary books are published, which are ample for the beginner. Some states have published most excellent pamphlets dealing with the local rocks and fossils.

There seems to be inborn in most of us a desire to make a collection of something at some period of our lives. Collecting stamps is probably the most common expression of this desire. As a side issue, we may add greatly to our interest in our hobby by making a collection of the minerals or fossils of our particular locality, and if we choose, we may exchange duplicates with collectors of other districts.

Collecting minerals or fossils has several real advantages over collecting stamps. The size of our stamp collection is determined largely by the size of our pocketbook, while the size of our collection of minerals or fossils depends upon the number of hours we spend out in the sunshine, in the open country

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poking around the rocks. Remember, we have access to just as much material and we can make just as good a collection of the material in our community as anyone if we will put the necessary effort into it. Also, nature does not discourage us by issuing a new series of fossils or minerals every two or three months.

Add to these the advantage that this book, our earth's diary, has not yet been completely read. There is a vast stretch of time—hundreds of millions of years perhaps—between the time when animal life first appeared on the earth and the time of the oldest fossils that have been found. And there are probably many species or varieties whose beginnings are recorded in the rocks that are now exposed and available for study, but whose beginnings have not yet been discovered because these early specimens are obviously rare and no one has yet had the good fortune to find one. There are, no doubt, many other species whose life cycles were short, or which were very restricted in the areas that they occupied, which are still unknown and which someone some day will discover.

The thrill alone that comes from merely finding a rare specimen amply repays your effort, and there is always the possibility that by such a find you may

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establish the birth of a species many millions of years earlier or its continuance many millions of years later than it was supposed to have existed. Who knows but that it will be your good fortune to find the clue, which, followed up, will ultimately unfold that great unknown past of which nothing is known today.

ADVENTURES WITHIN THE ATOMS

by DR. LOUIS N. RIDENOUR



DR. RIDENOUR was born in Montclair, New Jersey, and attended the University of Chicago. He received his Doctor of Philosophy degree from the California Institute of Technology. After six months at the Institute for Advanced Study in Princeton, he was, for two and one-half years, Instructor in Physics at Princeton University. In 1938 he became Assistant Professor of Physics at the University of Pennsylvania.



I. What Atoms Are

THE tremendous variety of form and structure and property found in the world in which we live has been shown by three centuries of chemical research to be due to the combination, in various proportions and under various conditions, of only about 90 different substances. These apparently primary substances, which long defied the most vigorous efforts of the chemists to break them down into simpler substances, are called the chemical elements. Familiar examples are oxygen, gold, iron, copper, nitrogen, hydrogen, carbon, and tin.

There are two possibilities regarding the ultimate structure of the elements: either each is continuous, in

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the sense that if one divided a bar of gold in two as many times as he pleased, the successively tinier and tinier parts would still show all the properties of gold, *ad infinitum*; or, on the other hand, an element is discrete, so that the imaginary dividing process just mentioned, if carried far enough, would finally reach the point where the last piece of gold would contain just one of the particles from which the gold was built, so that a further division would destroy the goldlike properties of the particle. By a long series of investigations, it was shown that the discrete view of the structure of matter is the correct one, and the tiny particles of which each element is built were named atoms, from the Greek for "uncuttable."

It proved to be possible for nineteenth century chemistry to measure a quantity which, for each element, was proportional to the weight of the atoms of that element, and when the elements were arranged in a table in the order of increasing atomic weight, periodic variations in their chemical properties were observed. This, coupled with the fact that the atomic weights of many elements seemed to be integral multiples of the atomic weight of the lightest and presumably simplest—hydrogen—led to the proposal, made in 1815 by Prout, that all of the atoms heavier than hydrogen were, in reality, built from hydrogen,

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and that careful measurements of atomic weights would disclose that the weights of *all* atoms were integral multiples of that of hydrogen.

Careful measurements of atomic weights subsequently showed that nothing of the sort was true, and the hypothesis of Prout fell into disrepute. At this stage, the physicists took up the problem of the structure of the atom, and it is largely their work which has led to our present view of the way in which atoms are built.

The daring hypothesis of Prout has been vindicated in the sense that all atoms are now known to be built of the same fundamental building stones, which are three in number. They are named the *proton*, the *neutron*, and the *electron*. The proton and the electron are electrically charged; they have charges equal in magnitude, but opposite in sign. The neutron, as its name implies, is electrically neutral. In the sense in which charges have been designated since the time of Franklin, the charge of the proton is positive and that of the electron is negative. All of these sub-atomic entities are astronomically tiny; the mass of a proton is roughly equal to that of a neutron, and each has a mass of about a millionth of a millionth of a millionth of a gram. (A 5-cent piece weighs five

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grams.) The electron is still lighter—about 2000 times less massive than the proton or the neutron.

By years of painstaking investigation it has been found that the atom of any chemical element is a structure somewhat resembling an incredibly minute sun and planetary system. At the center is a very tiny, positively charged nucleus, which corresponds to the sun in our solar system, and whirling about it, as the planets revolve about the sun, are one or more electrons. Now the protons and the neutrons that enter into the structure of an atom are all concentrated in the nucleus of that atom, and it is clear that the magnitude of the positive charge on a nucleus will be determined by the number of protons in the nucleus. In order that atoms be electrically neutral, as it is a fact of experience that they are, there must be as many planetary electrons outside the nucleus as there are protons in the nucleus. Since the electrical charges of proton and electron are equal and opposite, if this condition is satisfied, the atom as a whole will be neutral.

Now, it has been shown by experiment that the chemical properties of an element are determined wholly and solely by the number of planetary electrons the atom of that element possesses. Since this is so, and since the number of electrons the atom has is

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dependent on the number of protons in the nucleus of the atom, the problem of transmutation of the chemical elements has now been defined, if not solved. What is necessary is to add to or subtract from the number of protons in the atomic nucleus; the new nucleus thus formed will then gather around itself a number of planetary electrons equal to the number of protons to be found in its nucleus, and will have chemical properties entirely characteristic of this new number of electrons.

Gold, for example, consists of atoms of atomic weight 197. These atoms have nuclei possessing a positive charge equal to that of 79 protons, and therefore there are 79 orbital electrons whirling about the nucleus of the ordinary electrically neutral gold atom. Mercury, the next heavier element in the table of elements, has a nuclear charge of 80, and 80 extra-nuclear electrons. A mercury atom of charge 80 units and mass 198 units then differs from a gold atom of charge 79 and mass 197 only in that the mercury nucleus possesses one more proton. Any operation that would result in the removal of a proton from the nucleus of a mercury atom of mass 198 would change that mercury atom into an atom of gold.

So far we have not mentioned the neutron as an atomic building stone; but it is found that, in every

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case but one, the weight of an atom is greater than it would be if the atom were built only of protons and electrons. The additional weight is contributed by neutrons, which are packed in the nucleus together with the protons. In the nuclei of the light elements there are roughly equal numbers of neutrons and protons. You will see at once that, since the chemical properties of an atom are determined by the number of its orbital electrons, and since this number is determined only by the number of protons in the nucleus, the possibility exists that there may be atoms having the same chemical properties but different atomic weights, corresponding to different numbers of neutrons in the nucleus. It is, in fact, true that most chemical elements are built of mixtures of such atoms, which differ in weight, but not in chemical properties. This is the reason that most atomic weights are not integral multiples of the atomic weights of hydrogen.

The problem of transmutation of the atom, then, is that of producing a permanent change in the atomic nucleus; for, if an orbital electron simply be removed, the atom as a whole is left positively charged and will soon pick up an unclaimed electron from those drifting about in its neighborhood. This alteration of the nucleus is made difficult chiefly by two circumstances: the extreme smallness of the nucleus of an atom, and

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the intensity of the electrical forces that it exerts in its immediate neighborhood. While one expects tininess in atomic magnitudes, it is perhaps surprising that the nucleus of an atom is so small that a million million nuclei laid beside one another would extend less than a quarter of an inch. The atom as a whole, including its orbital electrons, is about 50,000 times larger.

Now, the way in which transmutations are effected in the laboratory is to hurl a stream of atomic projectiles moving with tremendous speeds—up to about a fifth the speed of light—at a target of the material in which the transmutation is to take place. Since the nucleus of an atom, as just indicated, is so very small an object in comparison with the structure of the atom as a whole, by far the greater number of the atomic projectiles spend their energy in collision with the extranuclear electrons. Only one in a million or one in ten million of the bombarding particles comes close to the nucleus of one of the target atoms. And here the second difficulty standing in the way of producing transmutation begins to be felt—the difficulty connected with the electrical forces in the neighborhood of an atomic nucleus.

You will remember that the nuclei of all atoms are positively charged; this is true also of the nuclei of the

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atoms used as projectiles to produce the transmutations. Usually, atoms of ordinary hydrogen, of heavy hydrogen, or of helium are used as bombarding particles, for the reason that these atoms, being the lightest of all, are most easily accelerated to the high speeds necessary for this work. When the positively charged bombarding nucleus comes into the neighborhood of the positively charged target nucleus, they repel each other strongly, owing to the electric repulsion exerted by like electrical charges on one another. Only if the bombarding nucleus has a great deal of energy—that is, if it is moving with a very high speed—will it be possible for it to overcome this repulsion and penetrate to the heart of the target nucleus. Therefore, since the positive charge on the target nucleus depends on the number of protons there present, and since the number of protons in a nucleus increases with increasing atomic weight of the chemical elements, it will be more difficult to produce a transmutation in a heavy atom, like gold or lead, than it is to produce one in a light atom, like carbon or aluminum. This proves to be true experimentally, and higher and higher energy particles are required to produce transmutations as one progresses from the lightest and simplest elements in the periodic table to the heavier and more complex.

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But should not the neutron, having no electrical charge, be able to enter all nuclei with great ease? It should—and it does. But because of this very fact, one does not find any free neutrons in nature; they are always combined into atomic nuclei. If one wishes to produce a stream of neutrons for use in transmutation experiments, he must produce the neutrons by a nuclear disintegration caused by charged particle bombardment, in which case the effects, just mentioned, of electrical repulsion by the target nucleus must be considered.

We have then progressed so far: to produce an atomic transmutation we must first shoot sufficiently many particles at a target so that there is a good chance of one of them making a close collision with one of the atomic nuclei in the target; then, when such a close collision occurs, the bombarding particle must have sufficient speed to overcome the electrical repulsion exerted on it by the charge on the target nucleus, and to win its way to the heart of that nucleus.

II. *How to Change Atoms into Other Atoms*

The nucleus of an atom is built entirely of protons, which have a positive electrical charge, and of neutrons, which are electrically neutral. Now everyone knows that like electric charges repel one another;

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this principle is, in fact, at the very basis of the phenomena of electricity. How is it possible, then, that the nucleus of an atom can be such a stable structure if it is built in this manner? The answer is, of course, that in order for this suggested model of nuclear structure to be a possible one, we shall have to postulate an attractive force of a very unusual character to act between the particles composing an atomic nucleus. This force must vanish at distances bigger than about a millionth of a millionth of an inch, for experiment has shown that at distances larger than this the force between two nuclear particles obeys the same well-known law as the force between two electrically charged pith balls—if the particles are of like charge, they repel each other. At the same time, the force which we are inventing to hold atomic nuclei together must, at smaller distances, be powerful enough completely to outweigh and overcome the electrical repulsion between two protons.

Now, it sounds as if this were a force entirely removed from our experience; and so, in fact, it is. It is only in the study of atomic nuclei that the scientist has to deal with distances small enough so that the existence of this force is required by theory or can be inferred from experimental results. And there is the

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best experimental evidence for the existence of this force that we have required for nuclear cement.

The way in which the scientist alters the electric charge of an atomic nucleus, and thereby produces a transmutation, is by hurling a stream of very rapidly moving nuclei at a target of the material in which the transmutation is desired. The smallness of an atomic nucleus in comparison with the size of the atom as a whole makes a close collision between the projectile and the target nucleus a rare event, and the electrical repulsion between the projectile nucleus and the target nucleus—since both are positively charged—requires that the projectile have a great deal of energy. Only if it be moving very fast will it be able to overcome this repulsion and reach the heart of the target nucleus, the region where the short-range attractive force just mentioned begins to come into play.

Suppose that a particle has sufficient speed to win its way through the electrical repulsion of the target nucleus and reach the heart of that nucleus. Then what happens? The answer is that any one of a number of things may happen. For a moment the target nucleus and the bombarding nucleus are fused together, but only for a moment. In the next instant, the compound nucleus formed by their coalition

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separates, usually into two fragments. One of these fragments may, in some cases, be identical with the bombarding particles, in which case we are not justified in saying that a transmutation has taken place. Oftener, however, neither fragment is identical with the bombarding nucleus, and, because the total number of particles in the two final fragments must be the same as the sum of the particles in the target nucleus plus projectile, if neither fragment is identical with the projectile, neither will be identical with the target nucleus.

Let us take an example. Suppose that we bombard a sodium target with nuclei of helium. Now all sodium nuclei found in nature are alike and have an atomic weight of 23. This signifies that there is a total of 23 particles in the sodium nucleus, of which 11 are protons and 12 are neutrons. The helium nucleus is one of the simplest and most stable of all and consists of two protons and two neutrons. In the favorable event that a helium projectile has penetrated to the heart of a sodium nucleus, the momentary compound nucleus thus formed consists of 13 protons and 14 neutrons. One of the things that may happen to it in the instant after it has been formed is that a proton may be ejected from it. This leaves behind a nucleus having 12 protons and 14 neutrons. The chemical

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properties of an atom having 12 protons in its nucleus (and therefore 12 extranuclear electrons) are those of magnesium, and our new magnesium nucleus has an atomic weight of 26, this number being the sum of protons plus neutrons in the nucleus. The proton that was ejected from the momentary compound nucleus is the nucleus of an atom of ordinary hydrogen. We have transmuted sodium into magnesium; and, incidentally, helium into hydrogen. This example is typical of all the transmutations now being brought about in the laboratory.

To produce an atomic transmutation, then, it is necessary to provide a stream of very swift nuclear projectiles, and several different means of providing them are at present in use. The first and simplest means is that of letting nature provide them. Certain radioactive elements in their decay shoot out very swiftly moving particles that are called alpha particles. These are in all respects identical with the nuclei of ordinary helium atoms, so that if an experimenter has at his disposal a sufficient amount of radium or other suitable radioactive element, he may use a stream of these swift helium nuclei to bombard a target and produce transmutations. It was in this way, by using the alpha particles from a decay product of radium to bombard nitrogen, that Lord

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Rutherford achieved the first genuine transmutation recorded in the history of science.

But radium and other radioactive elements are expensive, and the quantities available are small, while even the most energetic alpha particles emitted from a natural radioactive element are not swift enough to overcome the electrical repulsion exerted on them by nuclei of atoms heavier than those of potassium. What is desired is a way of producing a stream of nuclear projectiles at will, in the laboratory, without depending on the beneficence of nature.

In principle, the way of achieving this is obvious and simple. Like electrical charges repel one another, but unlike charges attract; so that all we need to do is to strip one or more of the orbital electrons away from each of the atoms that we propose to use as projectiles, leaving the remainder of the atom positively charged, and then attract these charged atom fragments to a negatively charged electrode. If this electrode has a hole in it, some of the particles will pass through, and they will emerge on the other side with a velocity that depends on the voltage to which we have raised the negatively charged electrode that attracted them.

Now clearly there are manifold difficulties connected with this scheme, or it would have been put

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into practice long ago. Rutherford produced the first nuclear disintegration in 1919, but it was not until 1932 that the first completely man-made disintegration was achieved. The biggest difficulty simply concerns the magnitude of the voltage that must be put on the attracting electrode. (I should say in passing that it is customary to accelerate the projectiles in several stages, but the principle remains the same. Several perforated electrodes replace the one mentioned above, and the total voltage is divided among them.) But in the "brute-force" method of acceleration we are discussing, the total voltage between the place where the projectiles are started and the place where the target is located must be at least 1 million volts to produce any but the simplest transmutations in the lightest elements, and the more millions of volts the better, if one desires to disintegrate moderately heavy elements.

There are several ways of producing such high voltages. First, one may simply extend ordinary electrical practice and build transformers that step up ordinary industrial voltages—say 15,000 volts—to several million volts, a potential that is then applied to a gigantic vacuum tube in which the particles are accelerated. This method has been used to supply voltages up to about $1\frac{1}{4}$ million volts, but

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is enormously expensive if that limit is exceeded, so far as present-day technique is concerned.

Second, one may employ what is known as a surge generator, in which each one of a large number of electric condensers is charged to a moderate voltage—perhaps a tenth of a million volts—and then all the condensers are connected together in series and discharged through the vacuum tube used to accelerate the particles. If there are 20 condensers, then one has 2 million volts available at the moment of discharge.

The third and last important method for “brute-force” acceleration of nuclear projectiles is that of building an immense electrostatic machine. A conducting sphere is insulated from the earth, and electric charge is continually carried up to it and deposited on it by an insulating belt that is driven by a motor. If the sphere is well insulated and proper precautions are taken to keep the charge from leaking off into the air by the purplish brush discharge called *corona*, and known to mariners and mountaineers as *St. Elmo's fire*, voltages of several million volts can be attained in this way. The largest machine of this sort that is now (1938) in operation works at 2.7 million volts, but several others are under construction which

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their designers hope will attain voltages of 5 to 7 million volts.

You will have inferred, from my reference to the foregoing methods of accelerating nuclear particles as "brute-force" methods, that some subtler means of producing high-energy particles for nuclear disintegrations exist. Of several schemes that have been proposed for providing high-energy particles without the necessity of actually producing and controlling high voltages, the cyclotron is the only one that is at present in use in nuclear disintegration work. When I last heard, the cyclotron at the University of California was producing nuclear projectiles whose speeds could only have been attained, using the "brute-force" methods of acceleration, by their fall through a potential difference of 8 million volts. And these particles were being produced by an apparatus in which the highest voltage employed is about 50,000 volts.

The explanation is relatively simple in principle but devilishly complicated to apply in practice. The positively charged atom-fragments which are to be accelerated in the cyclotron are drawn toward and through a negatively charged hollow electrode, exactly as in the other methods of acceleration; but in the cyclotron they are caused to move in a curved

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path which returns upon itself, so that they are accelerated by the same voltage on the same electrode not once, but many times.

If an electrically charged particle moves in a magnetic field at a uniform speed, its path will be a circle, and the faster the particle moves, the bigger the radius of the circle. Yet the relation between the size of circle and speed is such that the time required for a particle of any speed to traverse a semicircle is always the same. In other words, even if a particle's speed increases, it will always cross a certain diameter at certain, regular times.

This is the reason that the cyclotron works. For the voltage that accelerates the particles is not a steady one; it is rapidly alternating. And it is applied in such a way that it gives the particles a forward pull twice in each circuit of the apparatus. Because the time taken the particle to traverse a semicircle is the same for each trip, the particle arrives at the point where the acceleration is applied just in time to get another forward pull—that is, another increment in its speed. So around and around it goes, keeping step with the accelerating voltage, traveling in a sort of ever-expanding path, being accelerated twice in each complete revolution.

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The maximum voltage supplying the acceleration may be only 50,000 volts, but if the particle makes 80 complete revolutions it will have been accelerated by this voltage 160 times and will have an energy equal to that it would have gained by falling once through a potential difference of 8 million volts. Getting this apparatus to work for the first time was the neatest trick of the decade in experimental physics.

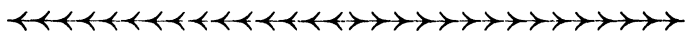
Powerful as these methods of bombarding atoms are, we must not expect that gross amounts of material are transmuted by them. As we have seen, the transmutation has to be performed an atom at a time, and there are many millions of millions of millions of atoms in a teaspoonful of water. There is the best of evidence that such nuclear transmutations may some day have profound world consequence. Yet, what the nuclear physicists are doing today is trying to find out how the universe is put together in the realm of the infinitely small.

PROBABILITIES AND IMPROBABILITIES

by FRANK BENFORD



M^{R. BENFORD}, born in Johnstown, Pennsylvania, was graduated in electrical engineering from the University of Michigan. For 18 years he was a physicist in the Illuminating Engineering Laboratory of the General Electric Company, and since 1928 has held the same position in the Research Laboratory of that company. A specialist in the problems of light and optics and the author of about 75 papers on engineering and scientific subjects, he is interested also in unusual applications of mathematics.



ONE would hardly expect to find a lesson in morals buried deep in the history of a branch of mathematics, but the history of the Theory of Probability contains such a lesson, although it has a slight left-handed twist.

A gambler in France wanted to know what the odds were in favor of a certain event he was betting on, and he took the problem to a Professor of Mathematics at the University of Paris. The mathematician found the answer, and at the same time he founded what is at once the most interesting and the most deceptive of the mathematical sciences. A lily of truth

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thus grew from the mire of professional gambling, and perhaps the moral is that good may occasionally come from evil.

After being conceived in a gambling house, it is only natural that the next development should come through another application to gambling. It seems there was a heads-or-tails game played with a single coin. If the patron of the gambling house won the first toss, he collected two roubles and got a second toss. If he won this toss he got four roubles and a third toss. The process of doubling the prize went on until the patron lost a toss and thus ended the game. At each toss the probability of getting another toss was just one-half, but to compensate for this the value of the next prize was doubled. The potential value of each toss was one rouble, and the potential value of each game was an infinite series of ones. The theory of probabilities therefore said that the patron should pay an infinite number of roubles for the privilege of starting a game.

Now, this demand for an infinite payment would have been bad for business, and besides, it just didn't make sense. Even the mathematicians balked at believing it. After expending some thought and several infinities of words, they arrived at an abstruse equation that brought the situation within the bounds of belief.

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These two events, one showing that there were simple ways of computing probabilities and the other showing that there was a more profound side to the subject, were the beginnings of a vast literature on Permutations and Combinations, Choice and Chance, and the Theory of Errors. One distinguishing feature of these branches of mathematics is the lack of certainty, as contrasted with the absolute certainty of other branches. The second feature is that probability deals properly only in large groups of similar events, while the other branches deal with single events or with small groups. As an example, if we were given the two sides of a right triangle, we could foretell the third side with accuracy and certainty. But the theory of probability will not tell us how a coin will fall on three successive tosses. The theory tells us what the average result will be if we make a large number of trials. There are eight combinations that may occur on three successive tosses, and there is no certainty that any one particular combination will occur. If a large number of trials are made, then the theory can predict with something approaching certainty that any one particular combination will occur in a certain percentage of the trials.

There is one popular view of the law of probabilities, as the man on the street reads that law, that either

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amuses or infuriates the mathematician. On a roulette wheel there are red spots and black spots. One system of gambling is to watch the wheel until red turns up three times in succession and then bet on black for the next turn. The idea here is that red having come up more than its due share of times, black must now come up in order to come out even according to the law of probabilities. This assumes that the wheel has both a memory and a conscience, and says to itself, "It is now time to be black for a few turns in order to play fair and fulfill the law."

This misuse of a perfectly good mathematical conception makes the mathematician see red and tear his hair, because he has written essays, treatises, papers, and books to show that past history has no such influence on future events. If the wheel is both accurate and honest, then each turn is wholly independent of preceding turns, and the chance for black remains exactly the same each turn, regardless of the number of successive appearances of red. Each turn is a complete event in itself and, like the humble mule, has neither pride of ancestry nor hope of posterity.

One of the most useful branches of probability is the Theory of Errors. If you stopped a statistician on the street and asked him, "How tall will be the next man to come around the corner?" he would say

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something like, "Five feet 9 inches, plus or minus 1 inch." This answer is not intended to be mysterious or evasive. It is a very definite answer that contains two facts. First, he has evidence to show that the average height of a man in that city will, according to statistics, be 5 feet 9 inches. Second, just half the men in that city will, according to statistics, be between 5 feet 8 inches and 5 feet 10 inches tall. The remaining half will be either shorter or taller than his 5 feet 9 inches plus or minus 1 inch. He therefore has really said, "It is an even chance that the next man to come around that corner will be within 1 inch of the average height, which is 5 feet 9 inches."

Only a few short years ago the theory of probability was but little used outside college classrooms, but today it has invaded nearly every science and every branch of engineering. One of the most useful applications is in the sampling of manufactured articles.

Suppose that a certain steel bar is to be 1 inch in diameter, but a variation of one-thousandth of an inch either greater or less than the exact inch can be tolerated. If 10,000 of these bars are made every day, it would obviously be expensive to measure every one of them in the routine of inspection. The theory of sampling indicates that if only a few of the 10,000 are selected at random and measured, the probability

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of, say, just one bar in the day's production being defective can be computed. If this probability is small, and only a few bars need be carefully measured, then it is evident that the theory has graduated from college and is in overalls in the factory, which is where all good theories finally find permanent employment.

Anyone dealing in probabilities must remember that the laws, derived for large numbers of events, can be applied safely only to events in bulk. And most important of all, probabilities are not *certainties*; they are mixtures, in known parts, of *probabilities* and *improbabilities*. Anyone thinking otherwise is due for an expensive education if he backs his opinion with money.

MEN AND METALS

by EARL R. PARKER

M^{R. PARKER}, a native of Denver, Colorado, is a graduate in metallurgical engineering of the Colorado School of Mines. Since 1935 he has been a member of the staff of the General Electric Research Laboratory, as a research metallurgist.

IF, SUDDENLY, something should happen to destroy all the iron on the earth, we'd be without automobiles and railroads. We'd lose our furnaces and plumbing. Nails and bolts and jackknives and axes would disappear. How would we manage to get along?

Would we all die? I think not. We'd be no worse off than our ancestors were three or four thousand years ago; for the history of our civilization and progress has been the history of the search for better tools, and it has gone hand in hand with the discovery of metals.

The first men of whom we have any trace knew nothing about metals. They must have lived almost half a million years ago, because the tools they used are found buried underneath the gravels left behind by the glacier that spread across much of our northern hemisphere. These tools are pieces of flint. They

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have been shaped for use, but so slightly and crudely that it is hard to be sure that they were not broken by frost, chipped by falling, or cracked by natural rock pressure. They are our earliest records of the Stone Age, which lasted in western Europe until only four or five thousand years ago.

Why did the Stone Age come to an end? Because our primitive ancestors discovered the use of metals. And that's where the story of Men and Metals really begins, as we try to trace the history of the growing use of metals by mankind.

When primitive man was looking for stones to use for knives and hammers, he, like a child, was attracted by pretty colors and curious shapes. Any bright object caught his eye as he wandered along the bank of the stream, which was his natural highway. And so, presumably, he found a glistening yellow stone. When he tried to hammer it, he found that it was soft—too soft to serve as knife or ax. So our Stone Age friend hammered his yellow stone into a ring or a bracelet, and wore it proudly as a decoration. This yellow stone was a nugget of gold. And because gold occurs free and uncombined in nature, it was probably the first metal discovered by man.

Now, silver and copper are two other metals that are sometimes found in the native, or uncombined

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state. And whenever a people have discovered for themselves the use of metal, the first metal tools have been made, wholly or in part, of copper. Hammered copper has been found among remains 6500 years old. But it took time to learn how best to use copper. Fully 2000 years passed before the early metal workers graduated from pounding bits of metal they picked up, and worked out a method of smelting copper from its ores and casting it in the form for use.

Probably the first reduction from ore came as an accident. We can imagine a campfire blazing on a hearth built of rough stones. One of these stones contains copper ore—in the form of copper oxide or copper carbonate. Copper ore, the glowing charcoal of the fire, heat—the ore is reduced to the metal. And the fire tender finds among the ashes an irregular lump of the precious red metal. It dawns upon him that he is master of a great and valuable secret—the secret of *making* copper.

Now, this discovery, which was important to our primitive savage friend, is equally important to us. For he had found one of the basic procedures of metallurgy, and from that simple discovery has come our great metals industry, with the civilization which rests upon it. The smelting of metal for the making of better tools hastened the clearing of forests. Better

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tools made possible better crops, the building of better houses, the construction of better boats. And, most important of all, it led to the discovery that other metals could be obtained by the same method.

But we are getting ahead of our story. After copper had been smelted, someone tried making a hole to collect the molten metal. Then this hole was lined with clay; then the floor of the hearth was enclosed with stones, arranged to form a wall. And that was the evolution of the metallurgical furnace.

Our primitive metalworker, familiar with the camp-fire, knew that a breeze made the fire burn brighter. So he fanned the fire. The natives of western Africa, today, use for this purpose fans made from tough grass and rushes. And then some mechanical genius, experimenting with a bag made from the hide of an animal he had killed, found that he could get a pulsating draft of air by squeezing the bag; and there was the bellows for the furnace.

But copper was still being made in lumps and then being hammered into shape. After a time—which may have been several centuries—someone noticed that, while the metal would soften and run, like fat or wax, when placed in a hot fire, it always solidified when it cooled; and that, also like fat or wax, it retained the form of the surface on which it was

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allowed to cool. So from that it was only a step to making molds and casting the metal into the finished form of knife or ax. Some of the cast axes and swords made in this way were very beautiful. They have been dug out of old graves in many parts of Europe. Preserved in museums, they compare, as works of art, with some of the finest works of modern artists. Because the copper commonly contained some tin, we call these relics bronze, and the age in which they were produced has been called the Bronze Age. But another metal was coming into use—a metal that gave its name to yet another age, the Age of Iron.

Iron ores are abundant; next to aluminum, iron is the most plentiful of the metallic elements in the crust of the earth. As long ago as 3500 B.C. the Egyptians had occasional bits of iron, which they used for ornaments. To them it was more precious than gold, and these pieces of iron were either fragments of meteors or the result of accidental smelting operations.

But the Iron Age did not really begin in earnest until iron was plentiful enough to be put to industrial use. This, in Europe, was about 700 B.C., when iron tools and weapons began to replace bronze. The primitive furnaces that had melted bronze were not hot enough actually to melt iron; but a spongy mass of metal was obtained that could be hammered or

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“wrought” into shape. And that, presumably, was the origin of “wrought iron,” which is in use today. Until the fourteenth century, wrought iron was the only form available. Then a blowing engine was invented that made possible enough heat to melt iron so that it could be cast. Therefore, it took some 2000 years to progress from wrought iron to cast iron.

Although, during the Middle Ages, steelmaking improved rapidly, yet there was one great mystery. Why did a piece of steel become hard and strong when it was quenched—that is, heated and then plunged into cold water? It took the microscope, almost in our own times, to fathom that mystery. Yet we find the answer simple enough. When the iron is hot, carbon is dissolved in the metal. When the metal is suddenly cooled, the carbon precipitates as fine particles of iron carbide. These particles act like little hard blocks or keys in the grains of the steel, holding the grains in position and preventing slipping and yielding.

The process of discovering things by accident did not end in savage, or even in medieval, times. Many of our metallurgical processes were observed long before science was far enough advanced to give an explanation. For instance, it has long been known that

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steel is brittle when certain structures are present. Science has shown that these structures are produced by the impurities, sulphur and phosphorus. It was observed that some steels remained bright, while others under identical conditions rusted badly. Again metallurgical science demonstrated that the rust-resisting steels contained impurities of nickel and chromium; and in addition to resisting corrosion, these steels were stronger and tougher than ordinary steels.

With discoveries like this, the science of metallurgy caught up with the metal industry and, instead of following and explaining, went out ahead and charted the progress of industry. Small amounts of different elements were intentionally added, to determine their effect on the properties of the steel. Nickel, chromium, silicon, and manganese, in small percentages, increase strength and toughness. Tungsten, vanadium, and chromium greatly increase the hardness. Molybdenum and tungsten give steel increased strength at red heat, so that boilers, stills, and turbines can be operated at very high temperatures. And the study and progress of alloy steels is going forward at an ever-accelerating rate.

If we look closely at our modern civilization, we see that it is built on a foundation of steel. Steel makes

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possible our skyscrapers, our vast railroad systems, our automobiles, all the electrical apparatus that gives us electric light and power. If we try to picture what our civilization would be like if iron were taken from us, in order to get an adequate comparison we have to go back to the days of the Stone Age and the Bronze Age.

THE USE OF LIGHT IN CHEMISTRY

by DR. GORTON R. FONDA

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DR. FONDA was born in New York City and was graduated from New York University. Later he attended the Technische Hochschule, Karlsruhe, Germany, where he received the degree of Dr. Ing. Since joining the staff of the General Electric Research Laboratory, in 1910, he has carried on investigations in chemistry and physics, many of them dealing with the problems of light production.

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THE chemist's concern is with the elements, 92 in number, which make up our world. We think of him as dissolving a thing up, testing it with different reagents, getting a precipitate so that we can finally conclude that the substance is made up of such and such elements. But frequently he finds that he can to advantage depend more on physics than on chemistry.

The first recorded case is of the Greek philosopher who was asked to find out whether the king's crown was or was not made of gold. Chemistry in those days was so limited that this poor man could think of no way to prove it. To cool his overheated brain, he

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tried a bath. When he slid down into the tub, which he had absent-mindedly filled full to the brim, of course an equal volume of water splashed over on the floor. At once he saw the solution. He need only weigh the crown, and get its volume by measuring the water that it displaced. The ratio would give the density. Then he could answer the king, for gold is twice as heavy as brass. Density measurements have been used ever since by the chemist in his analytical work.

An even more useful way in which physics aids the chemist is by means of the character of the light given off by substances when they are heated. Suppose a little table salt is sprinkled into a colorless flame. The flame turns a brilliant yellow—identical, in fact, with the color given off by the sodium lamps used to light highways. The cause of the color is in each case the same, for table salt is a compound of sodium, and in the heat of the flame it breaks up and the element sodium forms a vapor that becomes luminescent. Suppose that one used, instead of sodium, a salt of potassium—a very similar element. Then the flame would be colored violet. That distinction was discovered in 1760, and it has been made use of ever since in separating these two elements. But it was not until 100 years later that the next step forward was taken.

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Since Newton's day it has been known that, when sunlight is passed through a prism, it is broken up into the spectral colors. Around 1800 there lived in Bavaria a man named Joseph Fraunhofer. His father's trade of glazier led him to be interested in applications of glass other than simply for use in window-panes, and he found how to make better lenses. Then he turned his attention to prisms. He combined both prisms and lenses in an improved form of instrument, which gave an enlarged image of the spectrum. This was the origin of the spectroscope. It was so superior to Newton's simple prism that it stimulated the examination of spectra from all kinds of substances.

It was a German chemist, Bunsen, who finally developed a new use for the spectroscope. His name is familiar from association with the burner that he designed, still used in all laboratories and its principle applied to our gas ranges—the Bunsen burner. Bunsen was interested in the analysis of the famous cure waters from natural mineral springs. He realized that, coming from the earth's interior, they might very well hold in solution some new types of salts or even some new elements from minerals with which they had come in contact. These minerals had long troubled the chemist, for their analysis never added up to 100 per cent; something was evidently missing.

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It was in 1860 that Bunsen found what it was. Not content with examining the colors of flames into which these waters were sprayed, he turned the spectroscope on the flame. The spectrum produced was not the continuous bands of differing color that are formed by sunlight, but was made up of a succession of sharp lines. Sodium, for instance, gave a strong yellow line. Bunsen saw this through his spectroscope, and he saw the lines of other elements that he recognized. But, in addition, he saw two blue lines that were new. This gave him the clue to the presence in the waters of a new element. By chemical means he separated its salt and named the new element *caesium*, from the Latin word describing the blue of the heavens. This work of his in 1860 began the branch of science which in recent years has developed into that valuable tool—spectral analysis.

In fact, its usefulness began at once. It was found that the luminosity of a substance could be excited in ways other than by heating in a flame. An electric discharge through a gas was one way. At present, we have round about us many examples of gas discharges—mercury lamps, sodium lamps, and neon lamps. Neon, a gas, is one of a group of elements that we call the *rare gases*. Neon occurs in air, but only to the extent of about 1/10,000 of 1 per cent. Most of the

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other rare gases are even less plentiful in the atmosphere. Their separation was long and tedious, but its guide was the spectroscope, for it had by this time become recognized that every element has a characteristic pattern of lines scattered through its spectrum.

Light, like a radio signal, is transmitted through space as waves. Each color has a different wave length. Radio waves run in length from 600 to 1800 feet in the broadcast range, and down to 30 feet in the short-wave bands. But light waves are much shorter still—less than $1/30,000$ inch in length. The spectroscope is so sensitive that differences in wave length less than $1/1000$ of this amount can be measured.

This extreme sensitivity has made possible the discovery of new elements. Helium, another of the rare gases, is an example. It was first discovered by the Englishman, Lockyer, in 1868. He took advantage of an eclipse of the sun to examine with a spectroscope the characteristics of the glowing gases in the outer atmosphere of the sun. He discovered an orange-yellow line in its spectrum, and he was able to measure its wave length so accurately as to prove that it could come from no previously known element. Consequently, he concluded that it occurred only in the sun, and he named it *helium*, from the Greek word for sun. In the course of time, however, it was found also

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on the earth—first, in the gaseous volcanic eruptions of Mt. Vesuvius, then in radioactive minerals, and finally in air itself, but so extremely dilute that it could be detected only with a spectroscope.

There are other rare elements besides the rare gases. One group of them is known as the *rare earths*. Their separation is even more involved, and in this, too, the spectroscope proved its value. In order to vaporize them, it was necessary to introduce them into an electric arc. The discharge became colored, and its spectrum showed again characteristic lines of differing wave length. This not only guided their separation, but it led to the discovery of several new elements. Notable for his work in this field was the Austrian, Auer von Welsbach. He put his discoveries to use by devising a new type of light from illuminating gas—that of the gas mantle. We call it by his name, the Welsbach burner. It employs a finely woven netting of rare-earth oxides.

Further studies in recent years have shown the spectroscope so important for all analytical work that it has become a regular part of the chemist's equipment. It is quick, and it can detect an element in quantities as low as $1/10,000$ of 1 per cent. Its use is, however, limited to amounts of 3 per cent or less.

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An alternative method, which has yet to come into general use, can detect any amount. Instead of dealing with the visible or ultraviolet light given off by substances, it examines their X rays. X rays are formed when a substance is bombarded with electrons whose velocities are thousands of times greater than those in the arc discharges used to excite visible light. In contrast to the visible spectrum of an element, the X-ray spectrum has in it only a few lines, so that there is less chance for confusion. The substance to be tested can be smeared over the target of an X-ray tube. A simpler method is furnished by the Coolidge cathode-ray tube, from which high-voltage electrons are shot out into the open air through an extremely thin window of metal foil. In this case one need only place the substance to be tested in front of the window, with an X-ray spectroscope pointed at it.

X rays are light, just as are radio waves, only they are at the other extreme of the spectrum. They are several thousandfold shorter in wave length even than visible light. The spectroscope necessary for recording them has, therefore, to be of a different type. Visible light is broken up into its spectrum, not only by a prism, but also by what is called a diffraction grating—a succession of parallel lines ruled on a piece of glass or metal. The condition for its operation is that

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the distance between the lines must be comparable with the wave length of the light. How to get a satisfactory grating for X rays was a problem until it was solved by the German, von Laue, and the Englishman, Sir William Bragg. They found that a crystal could be used as a grating. Just as a pile of bricks is made up of layers, one on top of another, so a crystal is built up of layers of atoms. The distance between them turns out to be of the same order of size as the wave length of X rays. In this way a crystal of our common table salt became a refined scientific tool.

Perhaps this account of spectral analysis has served to emphasize how far the chemist has gone afield in the pursuit of his calling. It is no longer sufficient that he confine his attention to test tubes and reagent bottles. He has been obliged to apply himself to physics as well. He has had to broaden his outlook. He comes to realize that the domain of science is not fixed, but is always moving and finding new directions in which to move. This is a healthy attitude for anyone to acquire in facing a world that is changing as rapidly as our present one.

THE TIDES

by DR. FREDERICK W. GROVER



A^N OLD proverb reads, "Time and tide wait for no man." Those of you who spend your vacations on the seacoast know that bathing and boating engagements have to be arranged to suit the tide. Those whose activities lie upon the coastal waters have to take the rise of the tide into account in navigating shoal waters, steering their course to avoid or make use of the tidal currents. Year in and year out, the water recedes, uncovering rocks and shoals, only inexorably to return to cover them again and to creep up the posts of the dock or to hurl itself against the sea wall. Ceaselessly the cycle of ebb and flow repeats itself, neither hastening nor resting, while one generation of mankind follows another.

Even a short sojourn on the seashore teaches a few fundamental facts about the tide. On our Atlantic coast, high tide and low tide follow one another at regular intervals of a little more than 6 hours. If the time of one tide be noted, the next may be expected about $12\frac{1}{2}$ hours later. About the same interval separates the times of two low waters. Thus, there

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are two periods of high water each 24 hours, with two periods of low water equally spaced between them. The water level changes most rapidly and the water currents are most rapid halfway between high water and low water, while, for an appreciable interval around high water and low water, the current ceases and there is slack water in preparation for the reversal of the direction of the tidal current.

Furthermore, regular observations continued throughout a few weeks will show that, at times, the water level rises higher than normal only to recede to a lower point than normal. Those who know will tell you that these spring tides, as they are called, occur at the times of full moon and new moon, and they will be followed a week later, at the quarter of the moon, by high tides lower than the average accompanied by low tides where the water does not recede so far as usual.

It has been recognized for centuries, in fact ever since the centers of civilization began to press on from the nearly tideless Mediterranean to the shores of the Atlantic where the tides are well developed, that the changes that have just been outlined are connected in some way with the moon.

Perhaps the earliest existing account of the tides is that of Pliny, A.D. 77. Seven hundred years later the

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Venerable Bede, writing in northern England, records that the times of high tide may vary considerably between places separated by only moderate distances. But not until the discovery of the law of gravitation by Newton, in 1687, was a scientific explanation of the tides proposed. In his great work, the *Principia*, Newton proved mathematically that the attractive force of the moon and, to a less extent, the attractive force of the sun should suffice to explain the production of the tides.

The tide-producing forces, in fact, follow accurate astronomical laws. The moon exerts on the earth an attractive force that varies in magnitude from point to point. Since, however, the earth is a rigid body, the net effect is a pull equal to the average value, that is, the value that exists at the center of the earth. The pull of the moon on the portions of the ocean that lie, at the moment, nearest the moon is greater than this value, while the force on the water on the opposite side of the earth from the moon is less than the value at the center of the earth. These differences of force are only about one ten-millionth of the weight of the water—that is, the force by which the earth attracts the water to itself—so that the water is not lifted bodily away from the earth.

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However, only at points directly under the moon and those exactly opposite the moon, on the other side of the earth, is the moon's pull on the water exactly vertical. Everywhere else it is inclined to the vertical, so that it tends to move the water horizontally. Now, a very small force acting horizontally on a fluid is able to give it a motion along the surface, so that the water is raised above the general level under the moon and on the opposite side of the earth.

As the earth rotates on its axis, those regions where the water is heaped up maintain their positions with respect to the moon, and consequently there are two tidal waves moving around the earth. If the earth were completely covered with water, every point on the earth would be passed over by one or the other of these tidal waves every 12 hours and 25 minutes. The retardation of 25 minutes is explained by the motion of the moon around the earth, which takes $27\frac{1}{2}$ days and which causes the moon to come to the meridian of any place on the average 50 minutes later every day.

The attraction of the sun also gives rise to tidal forces. Although the sun is vastly greater in size than the moon, its distance from the earth is also so much greater that the solar tidal force is only four-ninths that of the moon. If it were acting alone, the sun

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would give rise to high tide at midnight and noon every day, with low tides at six o'clock in the morning and evening.

Since the tide-producing forces of the moon and the sun have different periods, they sometimes act in conjunction and sometimes subtract from each other. The former state of affairs occurs at new moon and at full moon, and gives rise to the *spring tides*; the latter occurs at the quarters of the moon, and the *neap tides* result. The tidal forces in these cases are, respectively, 20 per cent greater and 20 per cent less than the average. Also, the moon's tidal effect is greater when it is in *perigee* (that is, nearest the earth) and least when it is most distant (*apogee*). In this case also the range is some 20 per cent greater and less than the average. Spring tides that occur when the moon is in perigee and neap tides occurring at apogee represent the greatest possible extremes that can occur. A further modifying factor is the movement of the moon north and south of the equator during the month. This has the effect of giving rise to inequality of the two high tides that occur any day.

The laws of variation of the tide-producing forces are accurately known, and their values may be predicted at any desired time and for any place. The tides actually produced by these forces are, however,

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profoundly modified by the existing distribution of land and water on the earth. Consider, for example, the tides of our Atlantic seaboard. On the progressive wave theory above outlined, we should expect a tide of only a foot or two in range, which would occur later and later as the wave traveled westward. Actually, tidal ranges of 5 to 10 feet are common, and high water occurs practically at the same time all along the coast.

At the beginning of the present century, Dr. Harris, of the U. S. Coast and Geodetic Survey, pointed out that the tidal phenomena observed could be explained as manifestations of stationary wave systems set up by the tide-producing forces. As a simple example of what is meant by stationary waves, suppose one end of a rectangular trough containing water to be raised and then lowered again into its original position. A water wave will travel down the tray, will be reflected, and will return, continuing thus to move back and forth until it dies out. If, however, the end of the tray be lifted and lowered regularly at just the proper frequency, the water surface may be made to move rhythmically as a whole in such a way that when the level at one end is high, the other end is low, and vice versa, while the level of the water along a line across the middle of the tray neither rises

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nor falls. This line of stationary level is called a *nodal line*.

The same result may be obtained if pressure be applied to the water surface at one end at just those moments when the water level is starting to lower. Under these circumstances, a very small force, regularly supplied at just the right frequency, will sustain a large oscillation of the water surface. The period of the oscillation—that is, the requisite interval between impulses—is greater, the greater the length of the tray and the smaller the square root of the depth of the water.

Dr. Harris has mapped a number of regions of the ocean basins whose length and depth bear such relations as to make them responsive to the 12-hour-and-25-minute period of the semidaily cycle of lunar tide-producing forces. One of these regions abuts on the Atlantic coast line of the United States, while the nodal line runs northeast from the islands that form the eastern boundary of the Caribbean Sea. Tidal measurements taken on some of these islands show a very small range of tidal motion. A further confirmation of the stationary-wave theory lies in the fact that high tide occurs at practically the same time all along the coast. A still more crucial test of the theory is given by the fact that the tidal currents

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are zero at the times of high tide and low tide and greatest halfway between. If it were instead a progressive wave phenomenon, the tidal currents should be greatest at the crest and trough of the wave, and zero halfway between.

The stationary-wave hypothesis gives also an explanation of the tides of the Bay of Fundy, the highest tides in the world. The length and depth of the bay are such that its waters will respond most strongly to impulses having a period of about 12 hours, with a nodal line across the entrance of the bay. The forces of the rather large tidal oscillations outside the bay serve as the sustaining forces for the still larger oscillations of water level in the bay itself. Along its inner reaches, a tidal range of from 40 to 50 feet is common. Those of you who have visited Eastport, Maine, or Saint John, New Brunswick, will remember the great height of the piles of the docks. Most impressive of all are the vessels stranded on the mud flats at low tide in the Basin of Minas, Nova Scotia, and the amazing swiftness of the returning waters when the tide comes in.

Still another example of an unusual tide, although one of small range in this case, is furnished by the Marquesas Islands, in the Pacific, where high tides occur at about noon and midnight every day, and low

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tides at 6 A.M. and 6 P.M. Evidently, these are solar tides, and the lunar influence is negligible. These islands lie near a nodal line of one of the ocean basins whose period agrees with the $12\frac{1}{2}$ -hour period of the semidaily lunar attractive force—a striking confirmation of theory.

Accurate predictions of the times and heights of future tides, at the different ports, are of importance to mariners and pilots. These may be made by mathematical analysis of long-continued records obtained by tidal gauges. From these may be calculated numerically the effectiveness of the various tide-producing forces already discussed, and from these components may be computed the tidal movements to be expected in the future. Labor is saved and accuracy assured by performing this synthesis with a machine that automatically plots and combines all these component contributing influences. The U. S. Coast Survey has designed and has used for many years a machine that predicts and draws curves that take into account more than 20 separate influences entering into the existing tides. Almanacs giving the times of high tides and low tides and their heights for every day of the year are published, two or three years in advance, for all the principal ports of the country.

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Such data are accurate and dependable under all ordinary conditions of weather. In general, the effects of the winds are not important in their influence on the tidal heights. However, with winds of hurricane force blowing toward the land, the tide may reach heights entirely abnormal and unpredictable, as a number of tragic incidents have clearly proved. In such cases there are acting tide-producing forces quite unusual in magnitude and lying outside of the list of those orderly forces whose action we have been considering.

WHAT HAPPENS IN A GAS-DISCHARGE LAMP?

by CLIFTON G. FOUND

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MR. FOUND was born in Claremont, Ontario, and was graduated from the University of Toronto, where he carried on graduate study. He came to the General Electric Research Laboratory in 1916. During the World War he was engaged in research on submarine detection. Since 1925 his work in the Laboratory has been mainly in the field of electric discharges in gases.

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IN THESE days, with neon and mercury lamps glowing red and green and blue in advertising signs, and with sodium lamps casting their yellow light over many highways, there is no need to explain what a gas-discharge lamp is. But many a person, looking at such a lamp, has asked, "How does it work?" So let us see if we can answer that question. As an example to study, let's pick a sodium lamp, which delivers light of a golden yellow color.

The lamp itself is a glass tube containing metallic sodium—a tube into the ends of which are sealed two metal electrodes. One electrode, called the *cathode*, conducts the electric current into the lamp. The other electrode, called the *anode*, carries the current away

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after it has passed through the space. The air, of course, has been pumped out of the tube.

What carries the electric current across the space between cathode and anode? The same carriers that perform that task in a radio tube—electrons; for radio tubes, photoelectric tubes, and neon and mercury and sodium lamps are all electron tubes. They all depend for their operation on tiny elementary particles which have an electric charge.

The electrons may be produced in various ways. The electrons in our sodium lamp come from the cathode. When the metal of the cathode is heated to a comparatively high temperature, electrons are boiled off from the metal. When a positive voltage is applied to the opposite electrode—the anode—the electrons, which carry a negative electric charge, are pulled across the space and are collected on the anode. By this process, the space is made a conductor of electricity.

Although we have pumped the air out of the space, it is far from empty; for the metallic sodium that was placed in the tube evaporates under the influence of the heat that is applied to it—sends out, to fill that space, a seething mass of sodium atoms. In every cubic inch there are 60,000 billion atoms, all moving about madly, colliding with one another, and getting

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in the way of the electrons. And it is the interaction of the electrons with these sodium atoms that produces the light.

None of us can imagine even a million, let alone 60,000 billion. So, for a moment, let us try to visualize what happens when just one electron and one sodium atom collide.

An electron passing across the space from the cathode to the anode may be compared to a small boy running through a crowd. As the boy progresses, he is certain to collide with one or more persons. Now when he collides with a man, one of several things may happen. If the boy is moving rather slowly, he may merely bounce away from the man without doing more than change his own direction of motion.

However, if the boy is traveling faster, the force of the collision may be enough to disturb the man. For example, it may knock the man's hat off. If the hat is attached to the man's coat lapel by an elastic band, the hat will still remain in the man's possession, and in due course it will be returned to its original position on the man's head.

If, however, the boy is traveling at a still higher speed, the collision may be so violent that not only is the man's hat dislodged from his head, but the elastic band is broken. Then the hat and the man are

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completely separated, and the identity of the owner of the hat is entirely lost.

Before applying our analogy to the lamp, let me explain that an atom—such as a sodium atom—consists of a nucleus surrounded by several electrons, which are held to it by forces that may be likened to the elastic band on the man's hat. The magnitude of the force holding an electron to a nucleus differs for different substances, and the energy required to separate them is determined by the structure of the atom and is characteristic of that particular type of atom.

Now let's see how the electron resembles the small boy. When an electron, on its way between the cathode and the anode, collides with a sodium atom, one of several things may happen. If the speed of the electron is low, the sodium atom may be unaffected by the collision. Only the path of the electron is changed. A collision of this character is known as an *elastic* collision, and is of only minor importance in the production of light.

If the speed of the moving electron is sufficiently great, the collision may be so violent that the sodium atom is disrupted, or *ionized*. This term is used to describe the condition of an atom that has been disturbed to such an extent that one of the electrons composing the atom has been completely separated

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from its parent—just as the hat was knocked off and lost. In other words, the atom has been split up into an electron and a positively charged part, called a positive ion. We now have an extra electron that is free to collide with other sodium atoms. The function of the positive ion is to make the space between the electrodes a better conductor of the electric current. It behaves like a traffic policeman and permits high currents to flow at comparatively low voltages.

In our analogy we had a third case, in which the man's hat was dislodged but not lost. This too has its counterpart in the lamp. It takes place when the speed of the electron is higher than a certain critical value, but is still too low to cause ionization. When this type of collision occurs, the structure of the sodium atom is altered. One of the electrons of the atom is dislodged from its normal position. But it does not get far enough away from its normal position to become an independent electron. In this state, the atom is said to be *excited*. The displaced electron later returns to its normal position, and when this takes place—that is, when the hat is returned to the man's head—the energy that the atom received from the colliding electron is given out again in the form of radiation—in the form of light. In the case of sodium, this radiation is the characteristic yellow sodium light. Thus,

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an exciting collision puts the sodium atom into a state from which it is able to produce light. Therefore this third type of collision is the most important kind of collision in a lamp.

Now to return to our sodium lamp. It is not, as was pointed out earlier, merely an inert glass tube containing metallic sodium. It is a tube in which, every second, millions of electrons are leaving the heated cathode. These electrons are being speeded up by the applied voltage. They are colliding with many of the billions of sodium atoms in the space. Some of the collisions produce positive ions which aid in the conduction of the electric current across the space. Others produce excited atoms which are responsible for the production of light.

Of course, no one has ever seen a single atom. Probably no one will ever see an atom or an electron or a molecule. These particles of electricity and matter are far too small to be directly visible. But although the scientists who work with them do not strain their eyes and their tempers looking for them, they have plenty of evidence of their existence and of their complex interactions. And not the least of this evidence is the light emitted when millions of electrons encounter, every second, billions of atoms in gas-discharge lamps.

SCIENCE AND SUPERSTITION

by NEIL B. REYNOLDS



M^{R.} REYNOLDS, a native of Scotia, New York, was graduated in chemistry from Union College, and did graduate work in physics at Princeton University. He was for six years a research physicist in the General Electric Research Laboratory, was from 1933 to 1935 a member of the physics staff of the Massachusetts Institute of Technology, and since 1935 has been a special writer for the General Electric Company.



PHYSCISTS and chemists are fortunate. In their laboratories they deal with things that can be counted and weighed and measured, and they can repeat their experiments over and over to verify their results. But there are other scientists who are not so fortunate. Because exact, formulated knowledge is scarce, they have at times to fall back on such dubious information as is contained in superstitions and old wives' tales.

Chief among these scientists are the archeologists. Their laboratories are, literally, heaps of ruins. The experiments they study were performed centuries ago, and the records have been ravaged by war and earthquake, fire and plough. Yet the archeologists must

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gather up what poor, miserable fragments have survived, and from them reconstruct the whole history of the original experiments. It sounds utterly hopeless, doesn't it?

But the archeologists' success is a matter of record. From hut circles, broken pottery, a few badly preserved skeletons, a little jewelry, a lot of stone arrowheads, bronze and iron axes and knives—from such rubbish they have rebuilt the history of civilization. They have told us what we know of the people of the Stone Age; then, of races that had, somehow, learned to smelt the metal copper, and to alloy it with tin to make bronze; then, later still, of the same or other peoples who learned to smelt and forge iron—which brings us down to historic times and the Age of Iron, in which we are now living.

But let us see how superstition and folklore can aid in this scientific exploration of prehistory, and how science can help to explain superstition.

We speak of the four seasons: spring, summer, autumn, winter. Spring begins with the vernal equinox, about March 21; summer at the solstice, June 22; autumn at the fall equinox, late in September; and winter at the shortest day, or winter solstice, December 22. There's a good astronomical reason

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for choosing these dates, and they divide the year into four equal quarters.

But people didn't always use these days to mark the seasons—a fact demonstrated by Sir Norman Lockyer, the British scientist who discovered helium in the spectrum of the sun. Lockyer made a study of the alignment of Stonehenge, in England—that mysterious circle of towering great gray stones. He found that if he stood at the center of the circle and watched the sun rise on the longest day of the year, it rose almost but not quite exactly on the center line of a long avenue that leads up to the circle. It looked as though the people who built Stonehenge, very many centuries ago, had used the circle to keep their calendar correct, to mark the celebration of the official beginning of summer.

Lockyer, an astronomer, knew that the position of the rising sun at the longest day has been gradually shifting, because of a phenomenon known as the Precession of the Equinoxes. What was a perfect alignment a few thousand years ago would be out of line at the present time by a small but measurable amount. Actually, at Stonehenge, there was an error in alignment. So, assuming that the primitive astronomers who built Stonehenge had done a good job of

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observing the rising sun, Lockyer measured the existing error, made some calculations, and came out with the approximate date at which Stonehenge was erected—about 1860 B.C., or 3800 years ago.

But Lockyer found evidence also—confirmed at other prehistoric monuments—that people earlier still had used another calendar. By sighting over other, older stones, it was possible to determine the rising sun on the morning of the *first of May*. And here's where superstition comes in.

Divide the year into equal quarters, starting at May 1. You get, approximately, August 1, November 1, and February 1 as the other quarter days. The old pagan holiday, Lammas, used to be celebrated early in August. Hallowe'en falls close to November 1. Candlemas Day is February 2. And May Day is, of course, the first of May. In the celebration of each of these, there are customs that betray an ancient, pagan origin. And the evidence of stone alignment, supplemented by scraps of tradition, indicates that long ago these holidays marked the beginnings of the seasons: spring, summer, autumn, winter.

Baskets of flowers, on May Day, are certainly appropriate to the onset of summer. In parts of Scotland and Ireland, leases and contracts are renewed on

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Martinmas, early in November, an indication that the official year once began then. In Scotland, some local elections are still held on that day. Indeed, here in the United States, Election Day is "the first Tuesday after the first Monday in November," which may or may not be a coincidence.

And then Candlemas Day. If, on that day, the ground hog comes from his hibernation and does not see his shadow, spring is supposed to begin. Note that this takes place on February 2, which, according to the old May-November calendar, was officially the beginning of spring.

But if the ground hog does see his shadow on Candlemas Day, what then? According to superstition, the beginning of spring is delayed six weeks. And that six weeks brings it within a few days of March 21, the vernal equinox, the beginning of spring in our more modern reckoning. In other words, the superstition about the ground hog makes that animal decide, each year, between a calendar in use today and a calendar which has been abandoned at least 5000 years!

This may not be science, in the accepted sense. No scientist would credit that a woodchuck, by turning his back on the February sun, decides the seasons. We have lost our belief in all these superstitions—

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that is, many of us have. But, as a race, we have not forgotten them. And scientists, trying to piece together the history of mankind, trying to account for our psychology and some of the peculiarities of our behavior, find in such remembered superstitions clues that exist nowhere else.

STONES—PRECIOUS AND OTHERWISE

by DR. E. G. ROCHOW



IT's the little things that count in our modern lives. A tiny trace of a thing called a vitamin can prevent a disease; a few hundredths of a per cent of lead compound in gasoline can prevent its knocking in a motor; a small amount of a chemical compound in rubber keeps tires from cracking before they wear out. Science pays a great deal of attention to details, in order that our lives may run more smoothly, and many of us think of this as a strictly modern trend. It isn't. When we consider precious stones, for example, we find that the ancients set up some very fine distinctions between what was precious and what was not. They pointed out small differences on nonscientific grounds, and thereby started a long tradition in gems. It is interesting to apply some modern chemistry to the subject to find out what there is in a gem that makes it so valuable.

A gem is primarily a mineral. And since there is some latitude in the definition of minerals, let us limit ours to those inanimate substances that have a characteristic form and chemical composition that allow

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us to tag them with a name. Quartz is a very common mineral; every region has some local name for it. In the neighborhood of Schenectady it is found in the form of small, shapely crystals called Lake George diamonds, or Glens Falls diamonds, or Herkimer diamonds, or simply rhinestones. These crystals of quartz have considerable appeal and, therefore, have some value above that of the ordinary rocklike varieties. However, these quartz crystals sometimes have a rose color because they contain a small amount of manganese oxide, and we then speak of them as rose quartz and raise the price. If the mineral is colored yellow by iron, it is citrine, or false topaz; if it is colored purple, it becomes amethyst and the value goes up again. Obviously, these semiprecious stones are all alike except for small differences in chemical composition, and we must conclude that their appeal and their value lie in these traces of coloring compounds.

Why isn't quartz a precious stone? Well, for one thing it isn't rare. Quartz is in almost every igneous, sedimentary, or metamorphic rock; it forms the sand on our beaches and much of the dust in our atmosphere. It's too plentiful to be expensive. Furthermore, a gem material should be harder than quartz, so that it will not be scratched by dust. A gem must have also some fire or brilliance, and except in the case of

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the diamond, we usually demand some color also. Fashion may dictate the color, and it sometimes dictates the gem as well.

Color in precious and ornamental stones may be of two kinds—inherent or due to impurities. If the color is due to the main constituent and is therefore inherent in the composition, we call the stone *idiochromatic*. Azurite and malachite have their characteristic blue and green colors because they are basic carbonates of copper; turquoise is a lovely blue because it is a double phosphate of copper and aluminum. Many ornamental stones are idiochromatic minerals, but few gems are.

The local quartz that we mentioned was colorless in the pure form, and sometimes derived some color from small amounts of impurities. Minerals that are colored this way we call *allochromatic*, meaning colored by foreign substances. Obviously, the color is of little aid in identifying an allochromatic stone, and we must rely on other properties, such as density, hardness, index of refraction, and dispersion.

Among the really precious stones, the ruby and the sapphire are known to everyone. These are allochromatic variations of the mineral corundum, which is crystalline aluminum oxide. Most natural corundum is opaque and dingy, and while it finds use as an

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abrasive, called emery, no one values it for its appearance. If the corundum is a clear, flawless crystal, however, we call it a sapphire. White sapphire has a value of \$5 or more per carat. (The carat, you will remember, is two-tenths of a gram, and there are 2270 carats to the pound.)

Corundum makes a good gem mineral because it is very hard and has considerable brilliance. Therefore, sapphires have always been highly esteemed. If the stone happens to be colored blue by a trace of titanium, it is more valuable. Yellow sapphires are worth as much as \$125 a carat for the fine Ceylon stones, and yet these differ from the white sapphire only in that they contain approximately 0.92 per cent of plain iron oxide. The value of the iron as a coloring agent is, therefore,

$$\frac{120}{0.0092} \times 2270 = \$29,600,000 \text{ per pound}$$

The iron actually contributes this much to the value of the gem, and I think that you will agree that it is worth it. You will also agree that this is perhaps the most expensive iron in the world.

One never hears of red sapphires, because we call them rubies. The ruby is this same mineral, corundum, containing a small amount of chromium in such form

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as to color it red. A stone exactly similar in color and properties is made in some quantity by fusing aluminum and chromium oxides in such a way as to form a single crystal. Such synthetic rubies bring lower prices than the natural gems solely because they are not so rare. The coloring agent, chromium, is a common element, widely used at present in stainless steel and as chrome plate. As a metal it is worth about 80 cents a pound. As a coloring agent in natural ruby (which contains about 3 per cent chromium and is worth as much as \$1500 a carat) its value is

$$\frac{1500}{0.03} \times 2270 = \$113,000,000 \text{ per pound}$$

This is about as high as we can go in the price of coloring agents.

What about emeralds, which have long been favorite gems? The emerald is a variety of the mineral beryl, which is a beryllium aluminum silicate. The colorless mineral itself is not particularly attractive, because its index of refraction and its dispersion are so low that it has little sparkle or fire, and it is only moderately hard. When it is colored a light blue-green it is called aquamarine, and in some other colors it is called heliodor. The deep-green variety that we call emerald is very rare and expensive, and the appealing color is

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caused by a small percentage of chromium in the form of a lower oxide.

The mineral chrysoberyl is a beryllium aluminate and is therefore chemically related to the beryls. An interesting and popular variety is known as alexandrite, and this gem has the striking property of being an emerald-green color in daylight and a columbine red in artificial light. The marked change is due to strong absorption of yellow light, and to the fact that the stone is pleochroic, meaning that the absorption varies in the different directions in the crystal. A synthetic sapphire designed to imitate the play of colors in alexandrite is now being sold, and is made by fusing aluminum oxide with 3 per cent of vanadic oxide.

From a purely scientific standpoint it is difficult to understand why the mineral zircon is not used more as a gem material. In the colorless form it is next to the diamond in sparkle and play of colors, for it has an index of refraction and dispersion second only to that gem. It is not nearly so hard as diamond, however. There are some very attractive colors, including yellow, green, and blue. Uranium is one of the coloring agents. "Hyacinth" is the name applied to the yellow and orange varieties, but for the most part zircon has

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not been popular enough even to warrant a distinctive name.

It would scarcely be fair to talk about gems without mentioning the diamond, even though it is less interesting chemically than many of the other stones. As you know, diamond is a dense, isotropic, crystalline variety of carbon, capable of great brilliance and fire when properly cut. It occurs in many colored forms, but in contrast to most gem minerals it reaches its highest value when colorless. The sparkle and play of colors in a clear diamond are so marked that a permanent color detracts from its appeal rather than adding to it. Those stones that are absolutely colorless are called "first water," and bring the highest prices; good green, blue, and red tints are next in value, and the so-called blue-white stones are quite popular. The more plentiful yellow and brown stones are worth much less.

The diamond is outstanding in hardness as well as in brilliance, with the practical result that diamonds may be worn in rings for many years without perceptible scratching of the polished surfaces. The old Mohs scale of hardness used by mineralogists placed diamond at the top of the list with a hardness of 10, corundum next with an arbitrary value of 9, topaz next at 8, quartz at 7, and so on down to the very soft

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talc at 1. The intervals in this scale are unequal, and it is recognized that the step from corundum at 9 to diamond at 10 is greater than the entire scale from 1 to 9. It is now possible to measure the actual hardness of gems by an objective method, and the results are surprising to one used to the old hardness scale. If we establish a standard interval based on quartz at 7 and corundum at 9 and use this for our true scale, the hardest diamonds have a hardness of 42! There are some diamonds that will rate as low as 36 on our new scale, and then there is an impressive blank space until we come to boron carbide at 19. Carborundum will have the value of 14.

As some of you may know, all diamonds do not glitter. There are dark varieties, known as bort or bortz, which are crushed and used to polish other gems. Recently bort and poor gem stones have been adapted to cutting tools and drills, but the best diamond for such uses has long been the carbonado, a tough gray or black variety that does not fracture readily. A good black carbonado is worth more per carat than a poor gem stone, for it is better suited to do hard work, and a lovely appearance is of no use whatever. The demands for precision machining in the manufacture of automobiles and other products of our age have increased the demand for industrial

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diamonds enormously since 1920. In 1936 we imported 1,166,000 carats of industrial diamonds, and only 445,000 carats of cut gems, so that the industrial need now exceeds the aesthetic. Of course the value of the industrial stones is lower, despite the greater volume, for the workaday world has no need for the large, clear gems that are prized as jewels. It is interesting, however, that the great majority of diamonds entering this country now have laboring jobs to do, and the king of gems is no longer just an ornament.

CHASING THE MOON'S SHADOW

by DOROTHY A. BENNETT

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MISS BENNETT, a native of Minneapolis, was graduated from the University of Minnesota. From 1930 to 1939 she was with the American Museum of Natural History, in New York, where she was Assistant Curator of the Hayden Planetarium. She was Associate Editor of the magazine *The Sky*, coauthor of *Handbook of the Heavens*, published by Whittlesey House, and designer of the *Star Explorer*, a revolving star map. She organized and went as a member of the Hayden Planetarium—Grace Eclipse Expedition to Peru in 1937. In 1939 she returned to the University of Minnesota to be associated with the University Press.

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AS LONG ago as August 31, 1932 (the day of the last total eclipse visible in eastern North America) a group of us planned to be in Peru in 1937. And these plans began to be realized when, in April, 1937, the Hayden Planetarium—Grace Eclipse Expedition set sail for the south. Of course, it wasn't quite so easy as that. There were a good many hours spent in getting information about the eclipse, studying its path, learning the weather conditions, and trying to choose a suitable place from which to observe it.

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Strangely enough, finding any land at all was a real problem. There were only a few places along the shadow's path where there was land. The eclipse began at sunrise, way over near Australia, with just a few little islands in its path, and then it jumped nearly 6000 miles over empty ocean before it reached Peru.

Different observers chose different vantage points. The National Geographic-U. S. Navy Expedition selected Canton Island, near the sunrise end. Shortly after 9 A.M. the shadow of the moon carried the eclipse into the eyes of the instruments on Canton Island, remained for about four minutes, and then rushed on across the ocean to keep its appointment with Dr. Stokely and Dr. Stewart.

These scientists were in a boat cruising along the eclipse path, out where the sun was almost overhead. Theirs was the thrill of a hundred lifetimes, for they saw the sun completely disappear for *7 minutes and 6 seconds*—almost the longest time possible for an eclipse. There had not been an eclipse like this one in 1200 years.

Why was this eclipse so different? Because the various factors which always produce an eclipse were especially favorable. For example, not only was the moon directly between us and the sun, but it was also very close to us. When it came between us and the

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sun, and out behind it stretched a long, dark cone of shadow, that umbra or shadow more than reached the earth. It was, in addition, unusually wide in cross section.

I have said that the moon was near the earth. The distance varies because the moon does not move in a perfect circle around the earth. It can come as close as 222,000 miles, or be as far away as 253,000 miles. We usually say 240,000 miles as an average. In the same fashion, the earth doesn't move in a perfect circle around the sun, but is nearly 3,000,000 miles closer to the sun in January than it is in June. And that's another favorable factor that made this particular eclipse last so long. The moon was closest to us, and the sun was farthest away. Both conditions combined to lengthen the shadow and therefore the time of the eclipse.

The eclipse occurred near the equator—another favorable condition. You see, the time of totality at any one spot depends upon how long it takes the shadow of the moon to pass over. Only as long as the observer stands within the umbra does the sun appear totally hidden. The shadow moves very swiftly, actually about 2000 miles an hour. This motion comes from the motion of the moon in space, but it is necessary also to take into consideration the turning of the

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earth upon its axis, for this moves the observer under the moon's shadow. At the equator, the earth is turning fastest—close to 1000 miles an hour. And it turns in the direction in which the shadow moves. This means, you see, that a person at the equator will stay with the eclipse longer because he will ride along with it as the earth turns.

All these things, and many others, had to be known before we set off for Peru. We knew, for instance, that at Huanchaco, on the coast, the sun would be high, that the moon's shadow would strike there first, and that the sun should be hidden for 2 minutes and 33 seconds. (It was only out in the Pacific, near noon, that the eclipse time was unusually long.)

Therefore Dr. Fisher, of the Planetarium, with Mrs. Isabel M. Lewis, of the Naval Observatory, established themselves at Haunchaco to photograph the shadow of the moon as it first came in sight of land. But at this place there was likely to be coastal fog, so it seemed safer to scatter the members of the party. Therefore, a little farther south, nearer the center line of the eclipse and over 2000 feet in the mountains above the coastal fog, there were other members of our expedition: Dana K. Bailey, of Steward Observatory, and Dr. Serge Korff, of the Carnegie Institute of Terrestrial Magnetism. They had two telescopic

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cameras and a polar axis. The axis, with the aid of a driving clock, could turn the cameras backward as fast as the earth moved forward. This made it possible to keep the sun always in the telescope's view during these $3\frac{1}{2}$ minutes of totality. Such a pair of cameras, too, was at another mountain station farther to the south, under the direction of Mr. William H. Barton, Associate Curator of the Planetarium. There, at Cerro de Pasco, we were stationed 14,600 feet above the sea. At this location the sun was hidden for 143 seconds—less than $2\frac{1}{2}$ minutes. In Dr. Korff's station, near the center of the path and many miles closer to the noon position, the eclipse's shadow took longer to pass than at our station—longer too than for Dr. Fisher, for he was toward the *north* edge of the path of totality, where the diameter of the shadow was very small and its movement swift. Our station at Cerro was *south* of the central line and near the other edge of the shadow. It was moving rapidly here too, at sundown, almost ready to taper off the curved surface of the earth into empty space.

Somewhere between the Bailey-Korff station and Cerro was the broadcasting location, where Raymond Newby, of Columbia Broadcasting, had set up his equipment in the mountains. And then, 25,000 feet above the sea was Major Albert W. Stevens, of the

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U. S. Army Air Corps, in a Pan-American plane, to guarantee success in case of the failure of weather conditions at all the land stations.

To all these stations equipment had to be carried. It made a formidable list:

- 4 telescopic cameras
- 2 polar axes
- 2 driving clocks
- 2 small telescopes
- 3 chronometers
- 1 Fairchild air camera
- 7 motion-picture cameras
- 5 still cameras

Then there were two portable dark rooms, surveyor's transits, artist's canvas, observers' binoculars, and the complete broadcasting equipment. So, by four o'clock on the afternoon of June 8, the eclipse just didn't have a chance to escape us! There were 12 official watchers and an equal number of eager assistants.

At the Bailey-Korff station, five exposures were made with the 90-inch telescope, and six exposures with the 72-inch camera. One picture of totality on Kodachrome was made in the 72-inch camera, and an unusual color photograph of the scene of totality by Mr. Bailey with his small camera.

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Off at the seacoast, Dr. Fisher made continuous motion pictures, showing not only the total eclipse and the corona around the sun, but also the beautiful "diamond-ring" effect at beginning and end. And up in the mountains at Cerro de Pasco, eight exposures were made in each of the two big cameras. One of the long-exposure photographs at Cerro made by Mr. Barton shows tremendous extension of the coronal streamers and excellent detail in the inner corona. Motion pictures by Charles Coles show the progress of the eclipse, and a series of paintings by the artist D. Owen Stephens depicts the marvelous beauty of the scene with unusual accuracy.

From his 5-mile-high station in the plane, Major Stevens made pictures of the eclipse which have proved of great interest. In the clear air of the upper atmosphere it was possible to get unusual definition of the corona. On his pictures appears a uniform sphere of light about the sun that seems independent of the streamers that we have always associated with the sun's upper atmosphere. Investigation has verified, to the satisfaction of many, that this so-called Globular Corona is a real and definite characteristic form of the corona that had not been successfully photographed or investigated before. There are others, however, who feel that more eclipses must be studied before the

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globular sphere can be recognized as a physical entity.

And so, as you can see, everyone had plenty to do and had to work fast when the actual time for the eclipse arrived. And although, as Dr. Fisher often says, we didn't put all our eggs in one basket, but carried on various activities in five different locations, the remarkable thing was that every station had a perfect view of the eclipse!

Exciting as it is to prepare for an eclipse, to get the equipment ready, and to make the observations, there's really nothing that I can think of that is quite as remarkable as actually *watching* a total eclipse.

There you stand, with no sign that anything unusual is going to happen. The sun rises as on any other day. It climbs the sky from east to west; clouds may scud across the heavens; life goes on as usual. Then, all of a sudden, at the very second that the astronomers predicted, a black spot appears on the edge of the sun. As you watch, it creeps over the face of the sun and you realize that the invisible moon is becoming visible as it hides the sun.

Overhead the sky grows a bit darker; the landscape takes on a leaden hue; a breeze springs up from nowhere; the temperature drops, and you draw your coat about you. Off around the horizon the colors of sunset climb into the sky—yellow and rose and salmon

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pink. Overhead darkness seems to be falling, and out there the sun has almost disappeared. Finally, but a thin crescent remains.

Then, as the last bit of sunlight disappears, there is a brilliant flash. One small point of sunlight swells to a great brilliant spot, and all around the dark edge of the moon flashes forth a ring of light. It looks like a golden circlet set with a giant diamond solitaire. Then the diamond breaks into tiny chips and disappears, while out beyond the golden ring delicate streamers flash a million and a half miles into space.

Totality is here; the moon has completely hidden the everyday sun. But visible now is that wonderful, mysterious, unknown sun that is usually hidden in the brightness of day. It is actually the sun's upper atmosphere—thin gases that extend millions of miles, unknown gases that are seen so seldom, studied at such infrequent intervals, that they still puzzle modern scientists. Some would call them "coronium" and admit them to be unknown materials in the sun's corona. Others would label them "known gases existing under unknown conditions," and say they are oxygen and nitrogen and familiar terrestrial materials that exist on the sun under entirely different conditions.

We at Cerro had 143 seconds in which to watch this gorgeous sight. Into the pearly streamers of the corona

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licked rose-red flames of the prominences—50,000 miles. Really these were jets of hydrogen, helium, and calcium gases thrown off from the spots upon the sun's face. Appearing first on the eastern edge of the moon's disk, they blinked from view as the moon passed on, and then emerged upon the western rim and seemed to climb high into the corona as the passing moon left more and more of them in view.

And it was like night. Out in the dark sky Mars could be seen, and some of the fainter stars. All over the land darkness seemed to have fallen. The green hills had become purple, the sparkling lake dun-colored, the distant snowcapped peaks violet, and all about the horizon were the colors of the sunset or the dawn. It actually was both, for night had fallen in the midst of day.

But with the passing of the moon, a "diamond ring" flashed forth; shadow bands scudded through the air; crescent images appeared on the ground; and the whole landscape seemed bathed in the golden light of a mysterious and sudden day. Off in the distance the dark shadow of the moon retreated, sloping now at sundown, soon to slant off into the emptiness of space and leave no record of its passing except in the mind's eye of the fortunate observer, and on the silver coating of the photographic plate.

HOW YOUR RADIO TUBES WORK

by ELMER D. MCARTHUR

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MR. MCARTHUR, a native of Salamanca, New York, took his degree in Electrical Engineering at Union College. In 1925 he entered the Research Laboratory of the General Electric Company, and since 1930 he has been a member of the Vacuum Tube Engineering Department of that Company. He is the author of *Electronics and Electron Tubes*, published by John Wiley & Sons in 1936.

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THE high-vacuum tube's sole object in life is to control the flow of electricity through other pieces of electrical apparatus. That sounds simpler than it really is. It must be able to vary the flow of electricity in the circuit to which it is connected, smoothly, from zero to a fairly large value. The changes may be very small or very large, but in any event the tube must be capable of causing these variations almost instantly, with a minimum loss of power, and it must perform in exactly the same way every time it is used. In addition, the tube must perform its job under the guiding influence of another electrical circuit; that is, it must be an electrical device which, itself, is controlled electrically.

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When we speak of a current of electricity in a wire we actually mean the flow of electrons through the wire. Now, we know something about the behavior and properties of electrons, but we know nothing about the material from which they are made. We call it electricity. The flow of huge numbers of electrons, each carrying the same small quantity of electricity, makes up the electric current. Such a current will flow in a continuous metal wire connected to the poles of a battery. As long as the circuit is closed and the battery supplies pressure (which in electrical terms is called voltage or potential), the current will flow. It may be stopped by cutting the wire, just as you turn off your electric lights or your radio by opening the switch, and this leads us to the fundamental discovery from which grew the high-vacuum tube.

Why does opening the metallic circuit stop the flow of current? Is it because the intervening air is impervious to electricity? No, it is because the electrons cannot leave the metal to jump the open gap except under special conditions. One of these conditions was discovered by Edison while he was experimenting with an electric lamp having the ordinary hot filament and an additional metal plate near the filament. He found that when the filament was cold he could connect a battery between the filament and the cold plate and

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have no current flow. This result was expected. However, he discovered that current *did* flow around the circuit and through the more-or-less empty space between the filament and the plate as long as the filament was heated to a high temperature. Furthermore, he found that the current flow took place only when the cold plate was connected to the positive pole of the battery.

This phenomenon, which was called the "Edison effect," long lacked both explanation and application. It did show clearly that vacuum lamps, or bulbs, could be made to conduct electricity in one direction only—could be made one-way traffic highways for electrons.

In the years that followed, a number of distinguished scientists—men like Richardson, Dushman, Langmuir, Reimann, and Becker—studied this effect and explained it. Today a good deal is known about the emission of electrons from hot metal surfaces, although the studies still continue in many laboratories to discover better materials as sources of electrons.

In the huge high-vacuum tubes that supply the power for a broadcast transmitter, the cathode—which is the name given to the electrode from which the electrons leave—is made of strands of pure tungsten wire heated to a temperature of about 4000° Fahren-

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heit. Look at one of the tubes in your radio set. The glowing rod in the center is the cathode. It is a thin nickel cylinder coated on the outside with oxides of barium and strontium, and heated from within by a tiny heater. In addition to these two types of cathodes, there are several others better suited for other special types of tubes.

One of the first applications of the Edison effect was made by Fleming, who built small tubes each containing a hot filament and a nearby cold plate or anode. This early vacuum tube, called the "Fleming valve," was used by Fleming to receive radio signals. The radio signals brought to your receiver from your antenna are minute high-frequency alternating currents. We call such a current alternating because it first flows in one direction through the circuit and then reverses and flows the other way. This high-frequency alternating current makes the transmission of messages without wires possible, but it cannot be used without modification to operate a telephone receiver or a loud-speaker. It must first be changed into a pulsating direct current or, as we say, it must be rectified. Fleming recognized in the Edison effect the ideal rectifier for high-frequency currents.

This becomes clearer when we remember that the electrons can leave the hot filament and flow to the

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plate, but current flow in the reverse direction cannot occur; that is, electrons cannot leave the plate and flow to the filament.

Fleming's valves therefore produced just the right effect. The alternating-current radio signal flowing into the tube was changed to a current flowing in only one direction because the tube offered a closed circuit to current in one direction and an open circuit to current in the other direction. The ability of vacuum tubes to rectify an alternating current is not confined to radio signals. It can be used with very low-frequency alternating currents. In your radio receiver one of the vacuum tubes converts alternating current from your home power lines into the direct current needed by the set. In many of the receivers there is another small two-electrode high-vacuum tube performing essentially the same function as did the original Fleming valve.

So far we have seen how the electron current can be made to leave the hot filament. The question naturally arises as to what happens to the electrons, once they are free of the metal boundary. As I have pointed out, they flow across the empty space to the plate or anode and continue their journey around the circuit. They must have a reason for going to the anode, and this reason was supplied by the battery which Edison

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connected between the plate and the filament in his lamp.

When two separate pieces of metal are connected to the poles of a battery, electrons are pushed into one plate by the battery and drawn out of the other plate. Therefore, one plate has an excess number of electrons and the other plate a deficit. The plate having an excess of electrons is therefore charged to a negative potential, and the other plate carries an equal positive charge. That is the condition which exists at every open circuit as long as none of the excess electrons can escape. There is no steady current flow in the system—merely a static unbalance of the total number of electrons.

But there is a field of force between the two plates, called the electric field. It is the result of the attractive force between the two plates carrying charges of opposite polarity. If electrons were liberated from the plate having an excess, they would fall to the other plate through this electric field in much the same way that a released object falls to earth through the gravitational field of the earth. We have no control over the gravitational field, but the electric field between the two plates can be changed at will. It depends primarily upon the distance between the plates and upon the battery voltage. Higher battery voltages pack

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more electrons into one plate—at the expense of the other—and so cause a larger attractive force between the two plates.

Suppose, now, a battery is connected to the filament and the plate in such a way that it charges the plate positive by driving excess electrons into the filament. When the filament is hot, many of these electrons leave the filament and fall through the electric field to the plate. Ordinarily, not all of the electrons can leave. Only as many leave as can be drawn across by the electric field. This observation continued to be a puzzle until Langmuir pointed out that the electrons flowing through the empty space partially destroy the electric field, and that the flow of electrons away from the filament always adjusts itself to the amount required to reduce the field near the surface of the filament to zero. With this concept, it was but a short step to the formal statement of the law that governs the current flow between two electrodes. This law, called the space-charge law, states that for every value of electric field applied between the filament and the plate there will be a definite current of electricity.

This work also pointed out one of the needs for the high vacuum. The air, as we know, is made up of tiny molecules of several gases. These gas molecules and atoms, although they are very small, are huge com-

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pared with the much smaller electrons. If this gas were allowed to remain in the space between filament and plate, the electrons would have no chance of following a direct path to the plate. It would be like a hunter trying to shoot through a dense forest without hitting the trees. To provide an uninterrupted path, the air must be pumped out. Not all the air is removed, but enough to reduce the air pressure within the tube to about one-billionth of atmospheric pressure.

The other reason for the high vacuum is of course that, like a lamp, the hot filament would burn out in a few seconds if the oxygen were not removed.

Now we have seen that the electric field can be varied either by changing the distance between the electrodes or by changing the applied voltage. The greatest improvement in the old Fleming valve came from the realization that the electric field, and therefore the current flow, can be controlled also by voltage applied to other electrodes either in or near the space between the filament and the plate.

This idea gave birth to the modern high-vacuum amplifier tube. The additional electrode is a mesh of fine wires which completely surrounds the filament. This electrode is called the grid. In your receiving tubes the voltage applied between this grid and the

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filament controls the attractive force exerted by the anode.

Because it can modify the electric field, the grid can control the electron current that flows from the filament through the open spaces in the grid to the anode. Furthermore, the voltage on the grid has a much larger effect on the amount of current flow than an equal voltage on the plate. In other words, a small voltage applied between the filament and the grid will produce the same effect on the plate current as a much larger voltage applied between the filament and the plate. It is this property that permits the use of the tube as an amplifier.

In your radio set, the tiny alternating current picked up from the broadcast station is applied between the grid and the filament of one of the tubes. It causes a much larger variation in the current flow from the filament to the plate, and a correspondingly larger voltage in the electrical circuit connected to the plate. We say the signal has been amplified. Perhaps it is still too small. If so, it may be amplified again and again until finally, modified and amplified, it is fed to the loud-speaker and brings you your radio program.

THE MACHINERY OF HEREDITY

by DR. CARYL P. HASKINS



DR. HASKINS, a native of Schenectady, did his undergraduate work at Yale University and received his Doctor of Philosophy degree from Harvard University. He has been a member of the General Electric Research Laboratory staff, and a Research Associate at both Harvard and Massachusetts Institute of Technology. He now holds the post of Research Professor at Union College, and he is Director of the Haskins Laboratories, established in 1936. He is the author of the book *Of Ants and Men*, published by Prentice-Hall, Inc., in 1939.



THE phenomenon of inheritance is one which, from very ancient times, has captivated the imagination of men. Both because of its important practical applications to the welfare of the human race and its more fascinating theoretical implications, it has received a vast amount of reasonably disorganized investigative effort over a very long period of time. Very primitive man may ruin his potential crop wealth by selecting for generations from his poorest available stock, as does the Indian of the inter-Andean valleys when he habitually eats his best potato tubers, year after

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year, and reserves for planting only those not fit for consumption.

But man needs only to have reached a very low stage of civilization to realize what the principles of heredity, in general, mean to him. He needs but to be an Arab of an ancient nomadic group to preserve the pedigrees of his horses with meticulous care, or to be an Egyptian to guard jealously his best strains of wheat. At a more primitive stage than this he will preserve his own lineage with care if it be of the stock of leadership, fully convinced that, if his parents were of the caliber of kings, he too should qualify.

Vaguely and dimly, then, over an immense period of time, mankind has recognized and crudely used some principles of heredity. But progress in unfolding the details of the picture has been tremendously slow, for the problems involved are difficult ones, and their solution, or even the recognition of their existence, had to wait upon the development of suitable concepts and suitable tools. It seems possible that we stand today upon, or near, the threshold of a fuller knowledge of the processes of heredity than we have ever before.

Human characteristics, mental as well as physical, follow very definite courses in their transmission from one generation to another. Some of these courses are very simple, and are empirically, although not analytically,

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ically, well understood. Such things as color blindness, hemophilia, blondness, eye color, and hereditary feeble-mindedness follow simple and well-defined channels of inheritance, while stature and various other physical features and a number of mental talents are blended in a fashion not wholly understood.

Again, the manner of inheritance of physical features of size, weight, and configuration in animals and plants is vitally important to the stockbreeder or the agriculturist, and through him to the public at large. The breeder's ability to eliminate undesirable characteristics and to encourage desirable ones in the plants and animals with which he deals will be entirely dependent upon his knowledge of heredity in them. Other vital questions, of broader scope but less direct practical application, can be answered only out of a fuller knowledge of the nature of inheritance, of the chromosome, which apparently carries the hereditary material, and of the gene, which is thought to be the underlying unit of a single inherited character. The entire picture of the processes of organic evolution, with the resulting splendor and variety of the life of our earth, and of the fundamental nature of living matter itself, can never be achieved without a knowledge of the structure of the gene. And it is entirely possible that in the constitution of the gene, if it ever

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be thoroughly known, may be found the make-up of living matter.

For many years inheritance was thought of as a very stable thing. Characters might assort in different ways from parent to offspring, but they reappeared in essentially unchanged form, even if in different combinations. It was known that very rarely so-called *mutations* appeared—individuals that differed strikingly, and in no accountable fashion, from their predecessors, and whose own unusual features were transmitted to succeeding generations, thus setting up a new race. Discoveries of such mutations were attended with the greatest interest. Occasionally they were useful, but they were uncontrollable and unpredictable, and in number far too few to constitute other than scientific curiosities.

It was therefore of the highest importance for genetic theory when it was found, very shortly after the discovery of X rays by Roentgen in 1895, that, by irradiating the cells of plants and animals, such changes could be brought about within them that mutations, long regarded as rare and isolated phenomena, could be artificially produced in a number and variety previously undreamed of. After considerable preliminary work, which occupied the opening years of the present century, the new power has been put to

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good and striking use. Experiments with X-rayed tobacco seedlings, undertaken by Goodspeed and others in 1928, disclosed in a total population of 168 plants, 136 to be of wholly new types, with inheritable characteristics. Dwarf, low, and tall varieties appeared; varieties with large leaves or small leaves; those with dark bottle-green leaves or light gray-green leaves, with tough leaves or tender leaves, with light-pink, pink, or purple-red flowers. The variations in the flavor of the leaves must have been similarly wide, but it was too soon to test for this. Mosaic corn, white barley plants, barley "vines," tobaccos nine times the height of the normals, a cotton in which the seed is free of the lint, and potato tubers in which the normal period of dormancy has been broken, modifications in color and form of lilies, petunias, delphiniums, and many other flowers have all resulted from the numerous experiments in which X-ray genetics have been applied to agronomy. This, however, is but a beginning.

In the X-ray tube we have a single agent which, used in apparently the same way, or with only small perceptible differences of operation in different cases, can profoundly modify the course of life treated with it, stimulating it to increased productivity, deforming it, destroying it after a delayed interval, or blasting it instantly to death. How is it that such opposite results

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can be produced under similar conditions? Is there any way of segregating the good results from the bad and applying them in the service of humanity? What would be the financial benefits accruing from such a development?

The first two of these questions are extraordinarily difficult ones and have not been answered satisfactorily today, but the understanding of the remarkable phenomena involved has become far more complete of recent years, and the near future may possibly witness much further progress. To appreciate and evaluate the phenomena involved, it is necessary to consider what happens when a single cell, and especially the chromosomes and genes within it, encounters the shattering force of the X-ray beam and the electrons that it releases.

There is much evidence to indicate that, when the cells of an organism have been caused to mutate by an X-ray beam, or by other electromagnetic radiation of high quantum energy, the actual genetic changes have been brought about by the absorption in, or passage through, a genic locus of one or more electrons of the photo or recoil types. Very similar genetic changes can be induced by direct beams of electrons, or by particulate emanations from radioactive materials. Very recently it has been found that showers of neutrons—

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apparently chargeless particles of enormous penetrating power in most materials—can bring about similar effects. But beyond this strong suspicion, our knowledge completely ends, and the questions that crowd upon one another from the darkness are almost endless and nearly all vitally important.

What is the size of a gene? What sort of change is represented when a gene is mutated? Do all mutations require the same amount of energy, or can we select among them by the quantity of energy we apply, or in the way in which we apply it? What is the highest frequency with which we can cause a single gene to mutate, and why? Why have the genes heretofore been so enormously stable in the face of most modifying agents outside of radiations? Are natural mutations, which occur far too numerous, relatively, to be accounted for by natural ionizing radiation entirely, different from those that we produce in the laboratory? If we could alter the rate or character of mutational response in large groups of organisms, would we not modify in large measure the course of life on our earth? And then come the finer questions of detail and procedure, pressing on the heels of the more general ones. The list of things we want to know is apparently endless.

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These are all questions of grave difficulty, yet they are those which the biophysicist of today and tomorrow must solve; and great power over forces of nature—forces that at present are but haphazard and uncontrolled phenomena—awaits their correct solution. Slowly and painfully, yet steadily, a beginning is being made.

We have been engaged, for instance, in an attempted determination of the physical size of a given gene—the gene for the well-known character for white eyes in the fruit fly—using a method first fully evolved at the Institut Curie several years ago. It postulates that, if one shoots at the bull's-eye of a target with a machine gun and knows the distribution of his hits and the number of bullets that he fires on the target for each time that he reaches the center, then the size of that center can be calculated. Such a method tells us that this gene is about the size of a molecule of insulin—specifically, that it has a radius, if we wish to consider it a sphere, of four ten-millionths of a centimeter. This is not an unreasonable answer, and may be a useful one. We have gone on, in the same manner, to attempt to determine whether this gene is modified in the same fashion under the same conditions at widely separated temperatures.

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In another series of experiments we are using neutrons in place of X rays to check the effect of varying distribution of ions; and, in still another, streams of cathode rays to obtain a wide range of electron densities at dosages where time may be varied so as to maintain the total energy input constant. With the same tool, intracellular volumes other than genes can be investigated, and we have become interested in probing the molecular complex that gives to the nitrogen-fixing bacterium its marvelous power to obtain from the air, at room temperatures and pressures, the gas that man can fix in available form only at the expense of tremendous energy. Here, too, belong investigations of the nature of the complex of chlorophyll molecules that operate in manufacturing, from carbon dioxide and water and with sunlight for energy source, the sugars upon which we as a race wholly depend, by processes which at present we cannot satisfactorily duplicate.

Endless problems await the hand of the well-trained biophysicist and, especially, the X-ray geneticist. We have spoken of the practical work that he can do in the induction of new varieties of plants, and possibly of animals, in agriculture and stockbreeding work. We have touched on the powerful tools that he may evolve for the solution of such important theore-

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tical questions as the nature of heredity in man, the nature of organic evolution, and possibly the structure of life itself.

Succeeding years may well see us more and more dependent upon the minute forms of plant life—upon the yeasts for our nourishment, upon certain bacteria as aids to us in the manufacture of such chemicals as organic acids, alcohols, esters, celluloses, sugars, and resins. It will see us waging an ever-increasingly bitter attack upon the bacteria and protozoa that threaten our lives—the tubercle bacillus in its coating of lipoid material, the hemolytic typhus organism with its resistance to antitoxin, the conjugated diphtheria bacterium, the hosts of obscure protozoan fevers that contest the advance of the white man into the tropics. Little is known of mutation or heredity in the bacteria, but some very amazing phenomena apparently stand half revealed. Essentially, nothing is known of mutation in them under ionizing radiations. And herein lies a field, ready at hand for exploitation, which is filled with the richest rewards for the first comer, which is new enough so that the veriest layman may feel that his chance of contribution is nearly as great as that of the veteran in the field, and the scope of which is wide enough so that, in our present ignorance, we cannot delimit its boundaries.

FLUORESCENCE AND PHOSPHORESCENCE

by DR. GORTON R. FONDA



NEAR the close of the sixteenth century, in Bologna—that ancient city in northern Italy famous for its sausage—there lived a certain shoemaker. He made money at his trade, and then spent it in the study and practice of alchemy. Nowadays we look rather patronizingly on the alchemists as deluded souls, forever trying to convert common metals into gold. But we tend to forget that alchemy was an important stage in the growth of chemistry, and that the alchemists did much to advance the knowledge and practice of that science.

Even this humble shoemaker alchemist made a notable discovery. In the course of his laboratory experiments he found that a certain mineral, which he had picked up on the hills nearby, continued to shine brightly in the dark after previous exposure to light. Actually, this mineral was heavy spar, a barium sulphide. This was the first time that the phenomenon we now call *fluorescence* had come to anyone's attention. Other scientists of the age were greatly excited by the discovery, and called the mineral *Bologna stone*.

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Its fame started further studies. It was soon found that the fluorescent light excited from this stone had always the same color, regardless of the color of light used for its illumination—a notable observation that has since been found to hold fairly well for all classes of fluorescence. Then other substances were found that behaved similarly, not only minerals but also organic materials, such as the tincture of certain woods and leaves, and finally, solutions of the artificial dyes. Nevertheless, the accumulation of a definite and complete knowledge of the formation and behavior of fluorescence was slow.

For instance, it was not until about 1840 that Sir John Herschel noted the shimmer of blue fluorescence from a solution of quinine sulphate when it was held in the path of a strong beam of light, and then observed that the beam of light, after passage through the solution, was unable to provoke the blue light in a second solution held in its path. This was a clear demonstration that fluorescence is produced by light of one definite color, or, as we say, wave length. When that constituent color is removed from a beam of light, as was done by absorbing it in the first solution of quinine sulphate, then that which remains is unable to bring about any further fluorescence, although we still perceive it as a beam of light. It was not until 1852,

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however, that this was fully appreciated, and a complete statement was given of the nature of fluorescence by the English scientist, Stokes. It was he, by the way, who gave the phenomenon its present name of fluorescence, in honor of fluorspar, a mineral which had been found to exhibit it.

When a beam of light is passed through a prism, it is broken up into the spectral colors, ranging from red to violet. Extending down into wave lengths shorter than the violet there is radiation, invisible to the eye, but nevertheless very real. It is this that gives us sunburn and germicidal action—radiation appropriately called the *ultraviolet*, because it lies beyond the violet.

Now the color of a substance is due to the fact that it absorbs certain of these spectral colors. The portion that it does not absorb is passed on to the eye and perceived as the color by which we call it. Stokes found that fluorescence could be excited only by light whose color, or wave length, was such that it might be absorbed by the fluorescent substance. He found also, and it has become known as Stokes' Law, that the color of the fluorescent light given off is, in general, of longer wave length than the color of the light that excites the fluorescence. Take as an example the dye, rhodamine. Its solution exhibits a brilliant red color, and it has a strong absorption for green and yellow

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light. Now, examine a solution of rhodamine under green light; the solution appears a more brilliant red than ever. Experience will tell you that not every red solution does this. Try a bottle of red ink, which likewise absorbs the green and yellow. Placed under green light, it appears black. All of the green is absorbed by it, and since it does not fluoresce, no light whatever can be given off from it.

Not all fluorescent substances are excited by light whose wave length is so close to their fluorescent color. Take, for instance, the natural minerals willemite, which is a zinc silicate, and calcite, a calcium carbonate. Both are white in color. That means that they absorb no light in the visible range of the spectrum. Will they, therefore, show no fluorescence? Well, it is true that they will show none under any of the spectral colors ranging from red to violet. But we must not overlook the ultraviolet. And they do have an absorption for radiation in the ultraviolet. When exposed, therefore, to light from a quartz mercury lamp, their fluorescence flashes out in colors of startling brilliance—green for willemite and red for calcite. Not all samples of willemite and calcite are fluorescent, nor are they the only minerals that fluoresce. There are many others, each yielding fluorescence of a different color. It makes a fascinating chase, getting out into the

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hills, searching out minerals, identifying them, and then trying them out to see if they develop fluorescence.

Before we describe any further experiments, something should be said about how fluorescence occurs. Why is it that a substance should give off a colored light when illumined with light of a different color? An explanation is at hand the moment one considers what can be called the atomic structure of the substance, and then goes even deeper and examines the structure of the atom itself.

Suppose we are examining an office building. Seeing it first from a distance, our earliest impression is of its over-all shape, which was determined by the design of the architect. Similarly, a mineral sample at first glance is nothing but an object with a shape determined by the hammer blows that chipped it out. Closer examination brings out details in both cases. When we enter the building, we find it divided into square rooms about the same shape and size as those in every other office building, regardless of the exterior shape of the building, whether narrow and high or broad and long. Just so with the mineral. The X ray allows us to inspect its interior, and it reveals a regular pattern of compartments, just as regularly laid out as the rooms in a building. Each one of these compartments constitutes an atom.

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But the analogy goes even further. Each room of the building has people moving about in it, all actively engaged under the direction of an individual who remains always comfortably disposed in a large chair, quiet and dignified—the boss. Each of these people has a desk, which represents his headquarters; but occasionally the orders that he receives require him to get up and move somewhere else, perhaps to go to one of the wall cases to file a letter. An identical situation holds within the compartment occupied by the atom; for still closer scrutiny shows that the atom is made up of many individual units. Some of them, called *electrons*, are very active, constantly in motion. Like the workers in the office, they seem to be arranged in some orderly style about another unit, just as quiet and reposeful as the boss, called the *nucleus*. In addition to the normal activity of the electrons, as they are engaged at their desks, so to speak, some one of them will occasionally receive a message and, in response to it, move away—that is, go off to the walls.

Now it is this movement that is important for the development of fluorescence. It denotes what is known as excitation of the atom. It occurs in one of two ways: either in an electric discharge, where the atom receives an impulse from a free electron carrying an electric current and passes it on to one of its constituent

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electrons; or else by absorption of an appropriate beam of light, which can convey a similar impulse. In each of these ways the atom can be excited and an electron ejected. In each of these ways external energy is brought to bear on the atom—the force of a blow from an electron or the force of a blow from a beam of light. And in each case enough of this energy is transferred to an electron to hurl it out from its normal position to an outer one.

The next step is readily anticipated. When the electron bounces back to its normal position, like a ball on a rubber string, the energy received from the blow is given up. When this energy is thus released, it can reappear in two ways, as heat or as light.

If the substance is a gas, virtually all of the energy reappears as light, and in the simplest case this fluorescent light is of the same wave length or color as that of the exciting light. But in a solid the case is different. There are thousands of times as many atoms in any given volume of a solid as in the same volume of a gas. As a consequence of this crowded condition, there are thousands of times as many collisions or bumps between atoms in any given period of time. Collisions between excited atoms lead to a loss of their stored-up energy, so that some of it is converted into heat before it can be reemitted as light. Because of this loss, the

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fluorescent light is of lower energy content, so that it reappears in longer wave lengths than characterized the exciting light. In other words, it is displaced toward the red end of the spectrum.

Now we can come back to our organic dye, rhodamine. If a solution is made of it and exposed to green or yellow light, a strong red fluorescence appears. There is just one requirement—that the solution be extremely dilute. As it becomes more concentrated, the intensity of fluorescence falls off, finally decreasing to a mere trace in a concentrated solution. Solid rhodamine itself shows no fluorescence whatever. Why? Because under increasing concentration, molecules of rhodamine are thrown closer and closer together until finally an excited molecule loses all of its energy by bumps with its neighbors and has none left to emit as light.

A similar behavior is shown by the minerals. Some outstanding examples are zinc silicate and the sulphides of calcium, barium, and strontium, as well as of zinc. The common feature in all of these is the absence of fluorescence in the pure salt. They become luminescent only after fusion with some other metal, called an activator. The amount of this activator must be extremely small. Above 2 per cent, the fluorescence is lowered, and when the concentration becomes too

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high, the fluorescence no longer appears at all. Another case of too great concentration.

With some fluorescent salts, particularly the sulphides, luminescence continues after the exciting light has been removed. To this phenomenon is given the name *phosphorescence*. The electrons, which had been thrown out from their normal paths during excitation, give rise to fluorescence, as we have seen, when they return to their normal positions. In this case, however, their return has very evidently been delayed. There is such complexity within the molecule that the return of the electron becomes a highly involved process.

One can make these fluorescent minerals artificially. Silicates are the easiest, and anyone with a little laboratory equipment can try it. Take about equal parts of pure zinc oxide and silica, add about 1 per cent of manganese oxide, mix thoroughly by grinding, and then fire in a porcelain crucible at 1000° centigrade or higher for an hour or longer. Put a cover on the crucible and wrap some asbestos around it to retain the heat better. Then hunt up a friend who has a quartz mercury lamp and find out how strong luminescence you have been able to produce. Compare your sample with natural willemite. You may have improved on nature.

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So far, mention has been made only of the fluorescent minerals and the fluorescent dyes. But fluorescence is by no means confined to these. It is of frequent occurrence among the products of nature. As a consequence, it can be used as a means of analysis, in testing for purity or for adulterants. Butter shows a color different from that of margarine. Milk fluoresces, but only while fresh. Cheese shows a range of colors that vary as the ripening progresses. Lubricating oils fluoresce, and the color is different for those that tend to gum. Flour from different grains fluoresces differently. And here is an interesting test to distinguish between false and true perennials of rye. Plant the seed between moist filter papers so that it will germinate. In a few days rootlets form, and the paper absorbs from them some of their sap and acquires a stain. Test this stain for fluorescence. All the false perennials give a fluorescent stain, but the true do not.

Bacteria and fungi fluoresce, all of them differently. But the mere fluorescence from them is sufficient evidence of the extent of aging in meat and fish.

There is an interesting application of fluorescence that has a romantic tinge, and at the same time it opens possibilities for detecting alterations in legal documents and bank checks. It has to do with parchment.

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In Europe many centuries ago, parchment was treasured as the only available medium on which books could be written. A monk would do beautiful work copying out a book carefully, word by word, on parchment. But the next generation would consider his product not so worthy of immortality as some new book, freshly composed. So, because parchment was scarce and expensive, the carefully written words of the old book would be erased and a new book would be written on the old parchment. Was the original book then totally lost? Apparently, for no trace of it could be seen by the unaided eye. But fortunately the ink had left a colorless but fluorescent dye within the parchment, and when photographs are taken under ultraviolet, the film will often disclose the original as well as the later writing.

A GAUGE THAT MEASURES MILLIONTHS OF AN INCH

by DR. KATHARINE B. BLODGETT



DR. BLODGETT, a native of Schenectady, attended Bryn Mawr and the University of Chicago. After some years as physicist on the staff of the General Electric Research Laboratory, she continued her studies in the Cavendish Laboratories of Cambridge University, England, where she received the degree of Doctor of Philosophy. She is now associated with Dr. Irving Langmuir, in the General Electric Research Laboratory, studying the properties of thin films.



THE scientist in a laboratory is always measuring something. With his centimeter scale, his thermometer, his stop watch, and his chemical balance he is constantly measuring the quantities that control the progress of his experiment. Often there are a dozen different quantities that must be measured in a single experiment—quantities such as weight, volume, length, thickness, current, voltage, pressure, temperature, time, and many others. These measurements are the set of keys by which the work of one scientist becomes available to all scientists, for by means of these measurements the experiments that are per-

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formed in one laboratory can be reproduced accurately by workers in other laboratories. Thus, new experimental methods that are developed in Sweden, for example, are promptly reproduced, tested, and utilized by investigators in the laboratories of the United States, Holland, Japan, and many other countries.

I want to describe a method that is used for measuring thicknesses of a few millionths of an inch. Scientists need to measure very thin films of various substances, in order to understand the workings of many important processes. For example, when oil is used to lubricate two bearing surfaces, the question arises as to how thick the coating of oil must be to prevent the surfaces from seizing. Science has found that in the case of bearings that are operated at low speed, the lubricant need have a thickness of only one ten-millionth of an inch in order to lubricate the surfaces perfectly. The study of insulating materials, of photoelectric cells, of films of oxide on metal surfaces, and of many other problems is concerned with films that are too thin to measure by means of ordinary instruments.

A good micrometer gauge measures accurately a thickness of one one-thousandth of an inch. A very good gauge can measure one ten-thousandth of an inch. But the problem of measuring one millionth of an inch is entirely outside the range of micrometers.

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Fortunately, nature has provided an admirable solution. Everyone knows that when a soap bubble is blown until the wall of the bubble becomes very thin, the bubble reflects light of many colors. These colors are a special property of thin films. The colors seen in the films of oil that cover the puddles in the street after a rain are due to precisely the same optical property of thin films as the colors of the soap bubble. If you examine a film of oil spread on water, such as one of the oil films spread on a wet pavement, you see that the oil appears to be vividly colored in streaks and circles of yellow, red, blue, and green, although you know that before the oil spread out into a thin film it was certainly not bright-colored. Probably, it was crankcase oil that dripped from an automobile and its color was brown or black.

The variety of colors reflected by the oil when it is spread in a thin film is due to the fact that thin films sort out colors in the sunlight in such a way that a film of one thickness reflects yellow light, a greater thickness red light, a still greater thickness blue light. That is to say, the color is determined by the thickness of the film. Therefore, the rings and streaks of color exhibited by oil films on the pavement are in fact accurate contour lines, and their pattern constitutes an exact contour map of the film. The scale to which nature has

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drawn this map for our observation is amazingly small. For example, the thickness marked out by a red ring differs from the thickness of the adjoining yellow ring by only one millionth of an inch, yet an observer, unless he is color blind, has not the slightest difficulty in distinguishing the regions of different thickness.

The colors that are seen in thin films of oil and other substances are called *interference colors*. They occur for the following reason. When sunlight shines on the oil, two rays of light are reflected by the oil film; one ray is reflected from the upper surface of the film, and the other ray penetrates the film and is reflected from the under surface. The ray that travels the longer distance—that is, down through the oil and up again—therefore has to lag behind the ray reflected from the upper surface, which travels the shorter distance. When the thickness of the oil film is one-half wave length of light, the amount of lag that occurs causes the two rays to interfere with each other and produce no light.

Rays of light are waves similar to radio waves. They have many different wave lengths, and each color corresponds to a separate wave length. Therefore, when the optical thickness of the film is one-half wave length of blue light, the two blue rays reflected by the film interfere with each other and the film reflects no

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blue light at all. The action reminds one of the Gingham Dog and the Calico Cat that ate each other up. When all the blue light is removed from sunlight, the remaining light is yellow, so a film that has an optical thickness that is one-half wave length of blue light appears yellow. By the same token, a film that has an optical thickness that is one-half wave length of green light appears red. And so on.

Violet and blue light have the shortest wave lengths of all light that is visible to the human eye; therefore, the thinnest films in which interference colors can be seen have a yellow color. If you will examine the oil films in the street, to which we have already referred, you will find that the outermost ring is commonly a faint straw yellow, the color sometimes fading out at the edge to a region which has no color at all. In this region the thickness of the film is much less than a half wave length of any visible light.

The lengths of waves of light of different colors have been carefully measured by scientists and are known with very great accuracy. Light of the various shades we call blue has wave lengths ranging from 17 to 19 millionths of an inch; green light, from 19 to 22 millionths of an inch; yellow light, from 22 to 24; and red light, from 24 to 27 millionths of an inch. Using these values of the wave length, you can know

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the optical thickness of any region of a thin film by its color.

The most fascinating entertainment can be had with all sorts of colored oil films by a simple method. A tray or a large pan is needed which can be filled with water to the very brim. The rim of the pan should be waxed with paraffin wax so that the water can stand in the pan a little higher than the rim without running over the edge. Two or three flat bars of metal or glass, about half an inch wide and more than long enough to reach across the pan, should also be coated with paraffin. Place the pan on a table indoors, in front of a window, and in a position in which the water in the pan will reflect the sky but will not receive direct sunlight. (The glare from direct sunlight reflected from the water surface makes it almost impossible for anyone to see the oil films. Also the colors of the oil will appear far more vivid if the inside of the pan is black.) One of the best types of oil to use for the films is old oil taken from the crankcase of an automobile. New lubricating oil commonly does not spread on water, but old oil spreads very rapidly because of the oxidized substances it contains.

After the pan has been filled with water to the brim, scrape the surface of the water clean by placing one of the waxed metal bars across the top of the pan from

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edge to edge and sliding the bar along from one end of the pan to the other. Then place a very tiny drop of oil on the water from the tip of a fine wire. The oil will cover the surface with a film that is yellow, red, blue, or green, depending on the thickness of the film. Alter the thickness by sliding the bar along the pan and watch the colors change. If the film is initially red and you move the bar so as to allow the film to expand to a larger area, the film becomes thinner and instantly changes to yellow. If you compress the film, it changes to blue. If you compress it still further, it turns to green and then to yellow again. This second yellow film has about the same appearance as the first yellow film you obtained by expanding the film, but obviously it has not the same thickness. It occurs for the reason that the interference colors seen when the film thickness is one-half wave length of light are repeated when the thickness is increased to one wave length, and are repeated again at three-halves wave length. They are called the first-order, second-order, and third-order interference colors.

One of the uses that science has for interference colors is for the measurement of the thickness of films of oxide on metals. When a bar of steel or copper is heated in a flame, the surface of the metal turns to a straw-yellow color, then purple, then a deep blue.

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These are interference colors, and by comparing these colors with a standard color gauge one can know the depth of the oxide film.

Science has a color gauge to use for this purpose. The method of building the gauge was developed as a by-product of a study of the structure and behavior of certain types of molecules. When a small amount of stearic acid is placed on water, the individual molecules of which the stearic acid is composed endeavor to attach themselves to the water surface, with the result that the stearic acid spreads out over the water until each molecule has a place on the surface. Stearic acid in bulk is a white wax that looks rather like paraffin wax, but when it spreads on water in a layer one molecule deep the layer is so extremely thin that it is entirely invisible. The stearic acid molecule is shaped like a chain. It is made up of 18 carbon atoms forming the links of the chain, plus 36 hydrogen atoms and 2 oxygen atoms attached to the links. The entire length of this collection of 56 atoms is one ten-millionth of an inch. When the molecules spread on water, only one end of the chain attaches itself to the water, so that as the molecules crowd together the chains are forced into an upright position on the water surface. The molecules thus form a layer that has a thickness of one ten-millionth of an inch. By a dipping process the

A Gauge that Measures Millionths of an Inch

stearic acid can be transferred to a metal or glass surface, one layer at a time, and the successive layers are deposited on top of each other in such a way that a film can be built having any desired number of layers.

This is the method that is used for building the color gauge. On a piece of polished metal 3 inches long and 1 inch wide, films are built in a series of steps having thicknesses of 21 layers, 41, 61, 81 layers, on up to 201 layers. Therefore, the steps have thicknesses of 2, 4, 6, 8 millionths of an inch, up to 20 millionths of an inch. These steps appear as bands of bright interference colors. Films of iron oxide or of other substances are then matched in color to one of the steps of the gauge, and by this means the thickness of the oxide film is determined.

AN AMATEUR LOOKS AT ARCHEOLOGY

by P. SCHUYLER MILLER



MR. MILLER was born in Troy, New York, and was graduated from Union College, where he later took a graduate degree in chemistry. He has been Laboratory Assistant in the Department of Psychology of Union College and, since 1934, has been connected with public education activities in Schenectady, where he is now Adult Education Secretary, Schenectady Department of Public Instruction. He is an Affiliate of the Society for American Archeology and is Secretary-treasurer of the Van Epps-Hartley Chapter, New York State Archeological Association.



A SHORT time ago I had the doubtful pleasure of seeing Harold Lloyd, in a moving picture, give a hilarious impersonation of an archeologist in full cry after an ancient inscription. Let me say at once that I am not finding fault with Mr. Lloyd's acting. It is just that for the first time I saw myself as others must see me.

A man who persists in digging in the city dump for scraps of broken crockery, old shoes, and worn-out turkey wings is likely to be netted by the dogcatcher and locked up in the booby hatch. I know of no better

An Amateur Looks at Archeology

way to lose my friends than to start looking under their rugs and behind their doors for bent pins and lost collar buttons. But as an archeologist, those are just the places where I would be happiest. The innumerable little things that we use in our everyday life sooner or later wear out, or go out of style, or are lost, and they all turn up in the city dump, piled with old soupbones and broken bricks and sodden ashes, over similar mementoes that our parents and their parents before them left behind. Taken all together, layer after layer, they tell the story of our civilization during a period of a century or more—they do to an archeologist, at any rate. The Indian woman who swept the remains of her evening meal into a dark corner of the lodge frequently swept with them a bone needle, or a broken comb, or one of her husband's best fishhooks. Looking in places like these for the relics that will tell the story of an ancient people is plain common sense, and to my way of thinking common sense is the foundation of all science.

We Americans have a well-established tradition of relic hunting. The first settlers found themselves hobnobbing with a race without a history, whose only knowledge of their past was handed down from father to son in myths and tribal legends. Plowing the fields, the pioneers found relics of that forgotten past and,

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being even then born souvenir hunters, they began to collect them. What farm boy doesn't have a cigar box full of Indian arrowheads tucked away somewhere, or maybe even a few polished stone pieces set out on the mantel shelf to make other collectors' eyes glitter? For three centuries we have collected Indian relics as curios, without any thought for the story they could tell. Mounds have been blown open and village sites dug over, until they look like the aftermath of the Spanish war. Skillful forgers found that they could sell homemade arrowheads and axes to people who hadn't the time or the ambition to pick them up, and even today they are doing a rousing business in fake Indian relics. But in the meantime, a few exceptional men here and there throughout the growing nation were trying to puzzle out the meaning of the things that were being found. To them we owe the beginning of scientific archeology in this country.

Most people are thrilled by a good detective story. That is the thrill that archeology can give you. Every flint arrow, every broken potsherd, every buried hearth is a clue to the life story of the men and women who used and lost them hundreds or even thousands of years ago. By using the sense he was born with and whatever scientific ingenuity he can muster, our archeological detective can reconstruct the story that

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those relics tell, as Sherlock Holmes or Philo Vance reconstructs a crime. By carefully excavating a village site, he unearths evidence that helps him to form a picture of the daily life of the people who lived there—what they ate, what tools they used, even something of what they believed. A cemetery near the village may show him what the people looked like. Other similar villages come to light, and he gradually builds up the history of their relations with each other and with other hostile and friendly tribes. In the end, when all the clues have been found and all the deductions made, there emerges a grand, moving panorama of ancient races trekking across the face of the earth, struggling against hostile men and still more hostile nature, and gradually developing the characteristic way of life that is their culture, setting them apart from all other peoples.

The archeologist of today, whether he is studying the wonderful stone cities of the Mayas in Yucatan or the no less puzzling remains of the Laurentian culture in New York State, finds a use for every tool of modern science. A radio detector of the latest type will help him locate the iron traders' axes that were buried in the graves of the Iroquois clans during the colonial period. A new plastic compound developed for use in police work enables him to make molds of decayed fabrics too

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delicate to be taken out of the ground. His knowledge of geology and physical geography permits him to trace the ancient trade routes over which copper was brought from Lake Superior, shell from the Atlantic coast or the Gulf of Mexico, soapstone from Connecticut, and fine flint from Ohio, Pennsylvania, or the great prehistoric quarry at Cocksackie on the lower Hudson River. If there is no tool to suit his needs, he invents one. Unlike scientists in other fields, he can never repeat an experiment. History happens only once.

The story of American archeology today is the story of increasing cooperation between the professional students in the museums and universities and the amateurs who have only their leisure time to devote to their hobby. The museum men develop new techniques of excavation and restoration, uncover new problems, and ferret out the answers to old ones. But we amateurs know every square yard of the countryside where we live. We have surface-hunted every plowed field and dug into every refuse heap and corn pit for miles around. We know where to look for the threads of evidence that the professional needs to complete his tapestry of ancient times. And as our scientific curiosity is stirred up, we find that we are

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contributing something of real worth to the story of the American Indian.

Let me tell about a puzzle which has been tantalizing our own local chapter of the New York State Archeological Association. A few miles north of Schenectady is a large swamp known as the Consalus Vlaie. Old-timers can remember when there was a considerable area of open water at its center, but today it is fast filling up with sphagnum moss, tamaracks, dwarf spruce, and other bog vegetation. Recently, a group of local naturalists has been studying this swamp. They tell us that the plants they have found there normally grow only at much higher altitudes, or in a subarctic climate. This news revives the old theory that the Vlaie was originally a glacial lake, formed when the great ice sheet was retreating from eastern New York, and now transformed by the mosses that have crept out from its ancient shore line into a quaking morass that is a haven for wild life of all kinds.

It is only natural that primitive hunters would find such a place a happy hunting ground. There is ample evidence that ancient men once camped along its margin. Buried fire-places, masses of broken flint, and fire-cracked stone are easily found. Unusual types of implements have been turned up by the plow, some of

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them crude and some of them beautifully made. But who were the men that made them?

We know, from finds in other parts of the United States, that man did inhabit this continent at the close of the glacial period, 10,000 or 20,000 years ago. Were the men whose traces we have found at the Consalus Vlaie related to these first Americans, living here when the mastodon and the giant beaver still ranged through New York State? Were they the forerunners of the Eskimo, wandering down out of the North at some much later date? Were they the ancestors of the Mohicans and other Algonquian tribes found here by the first explorers? Or were they an unknown people whose existence we have never before suspected?

We hope that the naturalists can settle the question of how old the Vlaie really is. I have said that they find plants of a type that bears out the idea that the bog had its origin at a time when the climate was colder. A study of the shell deposits along the old shore line, such as has been made in Canada, may give us another clue to the age of the place. There are many such indirect avenues of approach, all of them worth trying.

But who were the people themselves? They left very little behind them, and that long ago. A layer of several inches of soil covers their hearths in some places. We must first discover what they did leave, and

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find out whether it fits into our scheme of ancient Indian cultures, as it has been worked out for this region. Even if their culture was not identical with any that is known, there may be indications that they were influenced or replaced by some known people. We have found no pottery; it may be that they had not discovered the art of agriculture. The flint they used was of poor quality; perhaps they had not lived here long enough to find the ledges that would yield the best material. Until we have excavated their camp sites beside the Vlaie and made every possible clue tell its story, we shall not know whether we are reading an uncut chapter in the history of man in America, or whether, as is probably the case, we are merely adding new information to the story of a people already known from other excavations.

Not everyone finds the science of archeology as absorbing as I do. Unfortunately, the magpie spirit is still with us. People ask, "What do you pay for arrow-heads? What is my collection worth?" The answer is, "Nothing—unless every piece is documented."

An uncatalogued collection of Indian relics is like a collection of paintings by unidentified artists. They may be beautiful, but who made them? You may be sure that you own a Titian, or a Rembrandt, or a

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Gainsborough. But do you? Can you prove it? The archeological value of any specimen is in the story it tells. The relics themselves are just so many pieces of cleverly shaped stone and bone.

The least that any serious collector can do, in his own interests as well as those of archeology, is to keep a catalogue of his collection and a map of the sites he has explored. Each specimen should be numbered and listed in a record book or on file cards, together with the place where it was found and any other information about it. For example, the fact that certain pieces were found together in a pit or grave would be very important, as would a note to the effect that you found potsherds only above the plowline on a certain site. Such information may give a clue to the relations between a whole series of ancient cultures. Thus, an Indian relic is like a dog; the longer its pedigree, the more it is worth.

Abroad, in England, France, Germany—in fact, throughout all of Europe—the amateur archeologist has long had a recognized standing. Many of the most outstanding contributions to our knowledge of ancient men have been made by doctors, lawyers, clergymen, or businessmen who have turned the casual curiosity of the hobbyist into the intelligent inquisitiveness of

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the true archeologist. Here in America there are opportunities, too—opportunities to contribute to our all-too-meager knowledge of prehistoric man on this continent. And the way to do it is to set out to be a real archeologist, instead of just another relic hunter.

IDENTIFYING MOLECULES

by DR. MURRAY M. SPRUNG



MANY persons are attracted to scientific study by the desire to understand, to imitate, and ultimately to improve on nature. The opportunity to better nature's handiwork is perhaps nowhere greater than in chemistry—particularly in that branch known as organic chemistry, where an understanding of certain of the principles upon which nature builds has made it possible to produce, synthetically, many substances that were once obtainable only from natural sources.

The purple dye, indigo, is an example. This valuable colored substance has, for centuries, been gathered painstakingly from plants by native workers in the Orient. Yet today almost all the indigo used is synthetic. Similarly, one of the most common of perfume essences, oil of wintergreen, was previously obtained only from the creeping plant whose name it bears. Today synthetic oil of wintergreen, known to chemists as methyl salicylate, is produced cheaply and in large quantities. And one might go on through a whole list of other substances of commercial importance—wood alcohol, carbolic acid, camphor, musk, alizarin, adrenalin, vanillin, and many more.

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The chemist is able to produce, seemingly almost at will, these and a host of other materials once obtainable only through the working of complex life processes. To be able to do so, however, presumes an abundance of previous experience and knowledge of the laws of molecular architecture; for certainly he cannot build anything without a key to the structure of the substance to be built. With this guide, however, he can proceed, on the basis of known principles, to put together the building blocks, or atoms, in the correct arrangement. His first job, then, is to establish the identity of the molecule he wishes to build—to know what atoms this molecule contains and how these atoms are linked together.

The branch of chemistry most closely concerned with the identification and building of molecules is organic chemistry—the chemistry of the compounds of carbon. And a broad field it is, for there are several hundred thousand known compounds that contain carbon, and each one is in some way different from all the others.

The study of organic chemistry received its first great impetus around 1828, when the first compound containing carbon was prepared artificially in a laboratory. It was a comparatively simple compound, called *urea*. Urea has the chemical formula CH_4ON_2 ,

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which means that it contains one carbon atom, four hydrogen atoms, one oxygen atom, and two nitrogen atoms, all bound together.

With this pioneering experiment as a pattern, more and more organic compounds were synthesized until, today, tens of thousands have been prepared. In this period, too, thousands of substances that occur in nature, but that have not yet been fabricated by man, have been studied sufficiently so that their identity—by which we mean their internal molecular architecture—is known beyond a reasonable doubt.

After obtaining a pure specimen of a substance to be identified, one sets about determining what different kinds of atoms are present in the molecule, and how many of each one. To answer the first question, a *qualitative* analysis must be carried out, making use of reactions that are characteristic of each chemical element whose presence is suspected. Then, to answer the second question, a *quantitative* analysis is made. This consists, almost literally, of tearing the separate elements out of the compound, one by one, and converting them into relatively simple substances that can be weighed or otherwise measured.

The next step is a little more difficult to follow, so let us tackle it with the aid of an example—a compound that is found in nature, and that may also be

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produced by a number of synthetic processes. The substance is a liquid and may be obtained in a high state of purity.

A qualitative analysis shows that it contains only three kinds of atoms: those of carbon, hydrogen, and oxygen.

A quantitative analysis shows that it is made up of about 48 parts of carbon, 12 parts of hydrogen, and 32 parts of oxygen, all in combination, of course. (As a matter of convenience we have expressed the composition of the substance in somewhat odd numbers rather than in the more usual parts per hundred. The reason for this will appear a little later.)

Now, before we can go any further, we must stop for a moment to consider one or two entirely fundamental chemical relationships. We encounter, first, Dalton's hypothesis, which underlies the whole of chemistry, and which we can accept without hesitation. It states that atoms exist, and that they cannot be altered by ordinary chemical means.

Our second rule—and it has been amply demonstrated—is that atoms combine to form molecules. When they do so, it is found that the ratio in which they combine—by volume, if they are gases—may be expressed by simple numbers, such integers as 1, 2, 3, 4, and so on. That is, *one* cubic foot of one gas

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may combine with *two* cubic feet of another, or *two* cubic feet of one with *three* of another.

If the elements that react are not gases, but liquids or solids, another simple rule is observed. The *weights* of elements that combine, whether solid, liquid, or gaseous, are perfectly definite and reproducible. Furthermore, the weights of an element which combine with two or more different elements are again related to one another as simple numbers. This rule is called the law of combining proportions.

Now, to show that it's not so complicated as it sounds, we'll take another example. Experiment shows that 16 weight units of oxygen combine with a certain weight of mercury, but that 32 weight units of oxygen combine in the case of tin, 48 weight units in the case of aluminum, and 64 units in the case of iron. Divide each of these numbers by 16, and you will get the simple numbers 1, 2, 3, 4. All the combining units of oxygen are simple multiples of 16.

The lowest weight of an element which enters into chemical combination is called its atomic weight. Applying this to oxygen, as we have just done, we find that the atomic weight of oxygen is 16.

This is the way all this applies to our problem of identifying molecules. Since compounds are made up of atoms, it follows that the weight of any given com-

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pound must be made up of the sum of the weights of all its constituent atoms. Therefore, if we know *what* atoms are present in the compound, and what percentage of each, we should be able to tell—bearing in mind the principles just discussed—exactly *how many* atoms of each kind are combined together in the compound.

So now let's return to our original compound, with its 48 parts of carbon, 12 parts of hydrogen, and 32 parts of oxygen. The unit or atomic weight of carbon is 12, of hydrogen 1, and of oxygen 16. Put these two sets of figures down together, as follows: 48:12:32—12:1:16. Inspection readily shows that if we divide the first set (the actual compositions) by the corresponding members of the second set (the atomic weights) we get the numbers 4:12:2. Since we have divided *total* weight by *unit* weight, we must have arrived at the number of atoms of each kind that are combined together in our compound. That means four carbons, twelve hydrogens, and two oxygens. Or simpler still, dividing by two, in our unknown compound every oxygen atom is associated with two carbon atoms and with six hydrogen atoms. Therefore, following the usual chemical notation, we may represent it as $\text{C}_2\text{H}_6\text{O}$, which is the simplest possible formula.

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It is the simplest possible formula for this reason. We have determined the *ratio* of the atoms, but we are not yet sure of the actual molecule. There might be twice as many, or three times as many, of each of the atoms—that is, it might possibly be $\text{C}_4\text{H}_{12}\text{O}_2$ or $\text{C}_6\text{H}_{18}\text{O}_3$, instead of the simple $\text{C}_2\text{H}_6\text{O}$.

To decide between these possibilities, we must now determine the *molecular weight*, which is the weight of a single molecular unit. One possible way to determine the molecular weight of our liquid is to vaporize it and find out how much heavier it is than a substance of known molecular weight. In the present case, the vapor turns out to be 1.438 times as heavy as oxygen gas. (An oxygen molecule is made up of two oxygen atoms and so its molecular weight is twice 16, or 32.) Therefore, the molecular weight of the unknown compound is 1.438 times 32, or very nearly 46.

The sum of the weights of the atoms represented in the formula $\text{C}_2\text{H}_6\text{O}$ —namely, the sum of 2 times 12, 6 times 1, and 1 times 16—is also 46. And so we have made sure that the simplest possible formula, $\text{C}_2\text{H}_6\text{O}$, is, in this case, the actual molecular formula.

So, by the use of ordinary arithmetic and a few fundamental chemical laws, we have tracked down the formula of our unknown compound. But we are not at the end of the trail yet. Before we can claim

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that we have actually identified it, we must discover how the atoms in the compound C_2H_6O are linked together. This part of the problem is not unlike trying to ascertain, without being able to see into the room itself, how a number of people are seated in a room. The chemical mystery can be solved only by studying the reactions of the compound—often a long and tedious process, but necessary in many chemical investigations. The experimental results can be summarized as follows:

1. Of the six hydrogen atoms present, one is different from the other five.
2. This hydrogen is associated in *some* manner with the single oxygen atom, since in various reactions they are removed together.
3. To determine how the remaining two carbon atoms and five hydrogen atoms are put together, we must use the so-called "rule of valence," which states that each carbon atom always has four other atoms, or groups of atoms, tied to it.

These are the clues from which we are able to piece together the solution of the mystery of our unknown compound. (Actually, the reasoning in such chemical problems is not much different from that used by the master detectives of fiction.) We can now sketch a rough diagram to show how the atoms are arranged.

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Imagine that the two carbon atoms and the single oxygen atom are attached together in a straight line, like three apples pierced by a stick. The first carbon atom has three hydrogen atoms attached to it—perhaps like three cherries attached by individual tooth-picks to the first apple. The second apple (or carbon atom) has two cherries (or hydrogen atoms) attached to it. The lone oxygen atom, which is the third apple on the stick, has the sixth and different hydrogen atom attached to it.

There, completely pictured, is our up-to-now unknown compound. In a few minutes we have indicated the steps which, in actual performance, might take many days of experiment and calculation. But what is the molecule that we have tracked down by so much effort? It is *ordinary grain alcohol!*

In a similar fashion we could build up, on paper, as many as we pleased of the several hundred thousand known organic compounds. We could describe the molecular structure of drugs, of dyes, of perfumes, of the natural or derived constituents of coal tar and petroleum, of the many important commercial chemicals that can be synthesized using lime and coke as the starting materials. If we were sufficiently skilled and sufficiently ambitious, we might attempt to identify the molecule of chlorophyll, the green

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coloring matter of plants, or of hemoglobin, the red coloring matter of the blood. Through just such efforts, the vexing problem of the nature of the vitamins has been partially solved. Progress is now being made in the study of hormones. We now know also a great deal about the chemical identity of rubber, cellulose, starch, and the protein substances—all of which are examples of the “giant molecules” of nature. A single one of these molecules may contain tens of thousands of individual atoms linked together.

When the enormously difficult problem of one of these giant molecules, or of the vitamins or hormones, is attacked, the method is fundamentally similar to the one we have outlined in studying alcohol. Whether the compound to be identified is found in nature or in a laboratory beaker, it must first be isolated, it must be carefully purified, it must undergo qualitative and quantitative analyses, its molecular weight must be determined, experimental studies of its reactions must be made. All these facts, when put together properly, will disclose the particular pattern in which the atoms are arranged. And all these facts, properly verified and correctly interpreted, can lead to only *one* complete picture of the molecule.

ELECTRON OPTICS

by DR. RALPH P. JOHNSON

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DR. JOHNSON was born in St. Pauls, North Carolina, attended the University of Richmond and the University of Virginia, and received his degree of Doctor of Philosophy from the Massachusetts Institute of Technology. He has held the position of physicist with the Geophysical Research Corporation, has taught mathematics at the University of Richmond, and since 1936 has been a physicist on the staff of the General Electric Research Laboratory.

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MOST of us, whether we realize it or not, are fairly well acquainted with electrons, the tiny ultimate particles of negative electricity. When we turn on an ordinary incandescent lamp, it is a current of electrons running through the tungsten filament that heats it white-hot. In the tubes of our radio, electrons evaporate out of a heated piece of metal, the cathode, and travel through the various grids to the collector. In the photoelectric tube, which opens doors, starts drinking fountains, sorts black beans from white ones, makes talking moving pictures possible, and does a multitude of other tasks great and small—there again is a current of electrons, set free by light—

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millions of electrons flying through a vacuum or through an atmosphere of argon, from one piece of metal to another.

“Optics,” the science of light, is also a familiar word, and the underlying principles of optics are matters of common experience. In free space, light travels in straight lines. But when a ray of light passes, at some angle other than a right angle, from one medium to another—from air to glass, for example—the ray is bent. Therefore, lenses can be made that will divert light rays as we wish, and telescopes, microscopes, cameras, and eyeglasses are possible.

The electron was discovered about 40 years ago, and the principles of optics have been known for more than two centuries. The phrase “electron optics” is, however, a comparatively new one. At first sight it is an odd combination. What connection is there between particles of negative electricity and rays of light?

Actually, the connection is a close one and a useful one. It has long been known that the paths of electrons traveling through space can be bent by electric and magnetic fields. Since electrons are negatively charged, they are attracted to a piece of metal that is positively charged, and they are repelled by a negatively charged piece of metal. This accounts for the bending

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that electrons experience when they travel through electric fields. And, since a flow of electrons is an electric current, electrons may be pushed sideways—that is, their path may be bent—in a magnetic field, just as the armature windings in an operating electric motor are pushed sideways by the magnetic field of the pole pieces.

A few years ago it was discovered that the bending of the path of an electron as it goes through electric and magnetic fields is exactly like the bending of a light ray as it passes through a system of lenses—the same mathematical equations describe both. Since this similarity exists, it is possible to make use immediately of all the knowledge, accumulated during two centuries, about the behavior of light rays, and to apply this knowledge to the behavior of the paths followed by streams of electrons. Such terms as “electron lens,” “electron image,” “electron microscope,” and “electron optics” become justifiable and useful.

We want now to look at two or three of the recent electron devices which have optical counterparts. First, we consider the “electron spotlight.” In an ordinary spotlight the rays that leave the lamp, in all directions, are collected and concentrated in a single direction. Analogously, the electrons emitted in all directions from a cathode, such as a heated piece of

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metal, can be focused into an intense narrow beam or pencil. When this beam strikes a screen of fluorescent material, a spot of light is formed. The electron spotlight tube becomes very useful when the beam, on its way from the focusing "lens" to the fluorescent screen, passes between a pair of metal plates or between the poles of an electromagnet. The beam may then be deflected up and down, or sideways, as the voltage on the plates or the current in the electromagnet is varied. The spot of light on the screen can thus trace out a graph of the varying voltage or current. The beam of electrons acts like the pointer of an ordinary meter, but with this difference: the beam can easily trace out variations that are much too rapid for any other kind of meter to follow.

This electron spotlight, which is usually called a cathode-ray tube, is one of the most useful tools of modern research. It may eventually become a very familiar, everyday object; for a cathode-ray tube, with an electron beam of varying intensity sweeping back and forth over a fluorescent screen, is one of the final image-forming devices in television receivers.

Electron beams are finding wide use also in the study of metal surfaces. If a narrow beam of electrons is directed obliquely against a solid surface, some of the electrons will strike the surface and then will be

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reflected away again. The direction in which these reflected electrons leave the metal is determined by the arrangement of the atoms at the surface. If the surface atoms are piled up regularly, like bricks in a building, the electrons bounce away only in a few definite directions. But if the surface atoms are piled up in hodgepodge fashion, the electrons are scattered away in many directions. Down below the surface the metal atoms are arranged in order—this is known from studies with X rays which, unlike the electrons, go so deep into the sample that the surface conditions make little difference. The experiments with electron beams, however, show that on some metals the surface itself can be changed from a regular array of atoms to an irregular array by the right kind of polishing operations. The hodgepodge surface is tougher and smoother than the orderly surface, and so is more desirable where two metals have to rub against each other. These studies of surfaces with electron beams are revealing how automobile cylinders, for example, can be made more resistant to wear.

The electron microscope is an important new device which involves electron optics. In one form, electron lenses are so arranged that an enlarged image of the cathode is formed on a fluorescent screen. By simply looking at the electron image on the screen, one can

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tell immediately which parts of the cathode are sending out the most electrons—these are the brightest parts of the image.

Later and more versatile types of the electron microscope do more. A beam of electrons is concentrated on the specimen to be studied, which is prepared as a thin film through which electrons can pass. Since different thicknesses and densities within the specimen transmit different proportions of the beam, the emerging electrons form a kind of shadow pattern of the specimen's structure. This emerging beam, by means of electron lenses, is magnified and made to focus on a fluorescent screen, producing an enlarged picture which can either be observed directly or photographed and then further enlarged photographically.

One limitation to the magnification of optical microscopes has been the wavelength of light; it is impossible to distinguish clearly objects much smaller than the light waves by which they are viewed. Because electrons behave like light waves of very much shorter wavelengths, the "resolving power" of an electron microscope can be made very much greater. Already many objects that were too small ever to be clearly seen with light-optical instruments have been photographed, in considerable detail, by this most promising application of electron optics.

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Strictly speaking, there is no electron telescope. There is, however, an electron-operated tube which behaves very much like a camera and which promises to have some applications in telescopic work. This tube has a photoelectric surface at one end and a fluorescent screen at the other, and between the two is an electron lens. When a light image falls on the photoelectric surface, the emitted electrons are focused by the electron lens onto the fluorescent screen, and the image is reproduced there. The photoelectric surface can be made sensitive to infrared light, which is invisible to the human eye. This tube, in effect, changes the invisible infrared image on the photo-surface into a visible image on the fluorescent screen.

And this is an unusual and a valuable accomplishment. It is not possible to allow the long-wave invisible infrared rays to fall directly on the fluorescent screen and to produce visible light on the screen. Converting infrared radiation into visible light, directly by a fluorescent screen, would be somewhat like stepping up to a change booth in a subway, presenting a nickel to the cashier, and getting a quarter in return.

Of course, the reverse exchange is quite possible. Thousands of people daily exchange quarters for nickels. Similarly, it is quite possible to let short-wave ultraviolet rays fall on a screen and there produce

Electron Optics

visible light. That is done often. The unusual behavior of this recent electron-optical tube is that, by means of a sort of "double play"—infrared to electron beam to visible light—we can, in effect, get quarters in exchange for nickels. At least we can, in this fashion, convert invisible infrared energy into visible light images. Infrared rays can penetrate through haze more easily than can visible light, so the use of this tube along with an ordinary telescope may extend the range of clear vision in hazy weather.

It is not to be thought that these developments of electron optics have all happened solely as the result of the discovery that light rays and electron beams follow the same mathematical equations. The discovery of this analogy has, however, pointed the way to new research in several directions, and has simplified the problem of nomenclature in a new, rapidly growing, and important branch of physics.

THE LIMITATIONS OF SCIENCE

by LAURENCE A. HAWKINS

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MR. HAWKINS, born in Pittsfield, Massachusetts, holds degrees from Williams College and Massachusetts Institute of Technology. In 1903 he went from the Stanley Electrical Manufacturing Company to the General Electric Company, where he was in turn a member of the Patent Department and the Railway Signal Department. In 1912 he joined the Research Laboratory, where he holds the position of Executive Engineer.

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MARVELOUS indeed are the advances of the physical sciences. Nothing seems beyond their ultimate grasp. We see the physicist reaching into the infinitesimal heart of the atom, transmuting one element into another at will. We see the astronomer reaching out into unimaginable space, measuring the distances to, and the motions of, nebulae a billion billion miles away. Chemistry is producing thousands of new materials for the service of man, while preventive and curative medicine and surgery are conquering one dread disease after another, and have lengthened the average span of human life by decades.

Applied science, by radio, flashes the spoken word half-way around the earth in a fifteenth of a second, or

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broadcasts it to a million listeners, or, by television, brings before our eyes events far removed from normal vision. Through electrical appliances, it has given us in the home, at the touch of a button, more comforts and conveniences than Aladdin ever dreamed of, and, through electric motors, has given industry the power of hundreds of millions of tireless slaves.

While no one man may know all that modern science has accomplished, yet there are widespread recognition and acclaim for the wonders it has wrought. Scientific achievement is generally esteemed as the highest manifestation of the human intellect.

But this generous esteem in which science is held carries a latent danger to science itself. Of late years the question has been asked, with growing frequency, why the aggregate brain power of our scientists is not applied to righting the grievous wrongs with which we are beset on every hand.

We have seen millions unemployed, dependent on relief, and thousands of factories operating on part time, while, even if they had been working overtime, they could not have produced enough to provide a comfortable living standard for all our people. We have seen farmers ruined by a glut of foodstuffs, while multitudes in our cities were going hungry. Looking abroad we have seen the horizon growing dark with

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storm clouds, conflicting political systems confronting each other threateningly, national antagonisms growing more acute, treaties no longer binding their signatories, and international law forgotten. Racial intolerances were adding fuel to the flames of passion. One ferocious war after another was breaking out, until now we face the threat of another world war, even more terrible and devastating than the last.

In such a crisis, when disturbances at home threatened our economic system and war abroad threatened civilization itself, why did not the army of science, comprising as it did so much of the brain power of the world, see its duty and come to the rescue? Why waste precious time in studies of ultra-macroscopic nebulae millions of light-years away, or of ultramicroscopic atomic nuclei, when there were acute problems pressing on every side, involving the happiness and lives of millions of fellow men? Why fiddle when Rome was burning?

The increasingly general belief that the scientist may be the savior of our distressed world, while flattering to him, can lead only to disappointment, and disappointment may change into hostility. Soon the public may be asking, "If science cannot solve our most direful problems, what good is it? Why

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spend millions of dollars on such futile institutions as scientific laboratories? Why not close them, divert the money to social relief, and let the scientist seek more useful employment?"

But reflection should show that the hopes that science may solve our domestic problems, social and economic, and may free us from the threat and horrors of war, arise from a faulty understanding of the scope and limitations of science.

The scientist is an explorer in the field of nature. He seeks new facts and new principles, which others, such as the engineer, the industrialist, the physician, or the educator may use for the good of mankind. He supplies, as it were, the raw materials for technological progress and for elevating our standards of living. He is like a mineralogist exploring for new mineral deposits. From the ores he discovers, metallurgists may produce better or less costly alloys, and automotive engineers may use these alloys to build improved motorcars for the public use. But the increase in the number of cars may give rise to new problems in traffic congestion; some may be driven carelessly or recklessly, with a steadily rising total of casualties; some may even be used by criminals for escaping from the scene of a crime, or taking a victim "for a ride." Acute problems may arise, but why look

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to the mineralogist to solve them? He has his own field of useful work, and, however able he may be, his special training fits him in no way for dealing with traffic problems or crime waves.

So too a physicist or a chemist may discover an important new fact which gives rise to a new industry, but which produces a temporary dislocation of older industries and increases unemployment for the time being. His discovery may even be used to produce a new and terrible weapon that further enhances the horrors of modern warfare. As an individual, he would doubtless deplore such unfortunate consequences of his labors, but as a chemist he can no more be held responsible for the misapplication of his discovery than could a manufacturer of surgical implements if one of his knives were used to commit murder.

Nor, as a chemist, can he reasonably be expected to solve the economic or military problems that arise, even if his own discovery has made them more difficult. As a chemist, he is not trained or qualified to be an economist or a statesman. We may need more and abler economists. If so, our only recourse is to train them. We do need more and abler statesmen. Our only recourse is in better selection and training. It is foolish to turn to the natural sciences to seek leadership in wholly different fields. To look to natural

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science for a cure for our economic and international ills is as unreasonable as to look to our economists or statesmen for a cure for cancer.

In one way, and in one way only, can the scientist help us in our economic, social, and international problems. His special knowledge qualifies him no better than the rest of us to set the world to rights. But if, by precept and example, he can teach us to adopt the scientific attitude, we shall be enormously advanced toward the solution of our problems. The scientist has learned that he must base his opinions solely on verifiable fact. No preconceptions, no emotional bias, no traditional or authoritarian dogma may be permitted to deflect his thinking. The clear light of established truth is his only guide.

Imagine what it would mean if we could approach our economic, social, and international problems with that attitude! Neither class prejudice, nor racial antagonisms, nor national hatreds could longer sway us. The emotional demagogue would be out of a job. Loyalty to true principle would survive, but loyalty to catchwords would disappear. Even selfish interest would be laid aside, while policies for the general good were being studied for their wisdom. Differences of opinion would be debated, without bitterness, not for the sake of victory, but solely to elicit the truth.

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Before such an approach, how many of our dangerous problems would solve themselves! How relatively easy would the solution of the rest become!

Not in our generation nor in the next can we hope for such a change in the mental attitude of the mass of men. But in time it may come. Not scientific knowledge, but the scientific approach, may in the end prove to be the savior of democracy and civilization.

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